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Propagation

A Journal of Science Communication

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A Journal of Science Communication

July 2010 Volume 1 Number 2

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Editorial

The maiden issue of 'Propagation' has received a great deal of appreciation by scientists, science communicators, science museum professionals and science historians. Notwithstanding this appreciation, I believe we can and must do more and keep striving to do better and better. When we started this journal we were self critical and at times skeptical as to how this journal while maintaining high standards would continue to attract the best of articles from eminent professionals. We are happy that our skepticism has made us strive that much harder to succeed in attracting scholarly articles which is evident from the current issue that contains twelve selected papers of contemporary relevance in diverse fields contributed by eminent professionals.

The first three articles are a tribute to the three towering personalities of India whose contributions, recognized internationally, have helped in the social and economic well being of the nation. The first article is a 150th year birth anniversary tribute to Acharya Prafulla Chandra Ray – a legendary scientist and the father of modern chemical research in India. The second one is our homage to another legend – Homi Jehangir Bhabha – the father of India's atomic energy programme, on the occasion of his birth centenary. The third article, which explores the views and philosophy of Rabindranath Tagore on modern science through his discourses with Warner Heisenberg, one of the founding fathers of modern physics, is a 150th birth anniversary tribute to the first Asian Nobel Prize winner and poet-laureate of India.

The article 'The Development of science centres in the Nordic Countries' describes unique experience of the science centre movement in Scandinavian counties of which the author has been a part for more than two decades. 'Science Communication – Mission Accomplished?' is an introspection of the science museum movement in India by an author who was one of the pillars of this movement for three decades. 'Museums – The Future Forward' is a futuristic projection by a senior museum professional. This article sheds light on how different the museum presentation will be in the years to come.

The science and society interaction has been illustrated in the article 'World War II and its Impact......'. It brings out many unknown facets of a very important technological development in post World War II era. 'Presenting Indian science and Technology Heritage ......' is a continuation of the article published in the previous issue under the same title. The first part of the article has been well appreciated by scholars. The article 'Incorporating visitors' experience......' contributed by two senior exhibit designers emphasizes on the importance of visitor oriented exhibit development and discusses a case study.

There are three articles on science centre exhibits written by senior curators of NCSM. The exhibits – 'Foucalt's Pendulum' and 'Mechanical Television' have historical importance. But their reproduction in science centres involves intricacy and technical challenge which the authors had successfully met. The 'Double Gravity Well' is also an important problem in physics. The exhibit was developed in a rather unconventional way – through mathematical modeling.

We hope that the second issue will equally satisfy the reader as the first issue did so. We welcome constructive suggestions for improvement of the journal.

Jayanta Sthanapati
Chief Editor

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Volume 1, Number 2, July 2010

CONTENTS

Page

Editorial 81

Contents 82

Acharya Prafullachandra Ray : Life of a Legend .... *Syamal Chakrabarti* 83

Remembering Homi Jehangir Bhabha .... *Mayank Vahia* 89

Tagore's Cosmic Scepticism and Modern Science .... *Ashish Lahiri* 92

The Development of Science Centres in the Nordic Countries .... *Asger Hoeg* 99

Museums : The Future Forward .... *George Jacob* 104

Science Communication: Mission Accomplished? .... *Ingit Kr. Mukhopadhyay* 109

World War II and its Impact on the Studies of Magnetic Resonance : 1939-1973 .... *Jayanta Sthanapati and Kunal Chattopadhyay* 115

Presenting Indian Science and Technology Heritage in Science Centres (Part II) .... *Shivaprasad Khened* 124

Incorporating Visitor Experience into Exhibition Design - Deconstructing a Student Project .... *Gretchen Jennings and Karen Lee* 133

The Making of India's First Short- Length Sustained Foucault Pendulum and the New Design .... *E. Islam* 145

Development and Mathematical Analysis of Double Gravity Well Exhibit .... *Indranil Sanyal and Nataraj Dasgupta* 160

Developing a Mechanical Television .... *Abdullah Mondal* 165

Acharya Prafullachandra Ray: Life of a Legend

Syamal Chakrabarti

The nineteenth century Bengal witnessed the birth of many illustrious characters. To name a few are Pandit Madhusudan Gupta, Radhanath Sikdar, Mahendralal Sircar, Iswarchandra Vidyasagar, Akshoy Kumar Dutta, Rambrahma Sanyal, Pramathanath Bose, Girishchandra Bose, Rajendranath Mukhopadhyay, Jagadishchandra Bose, Rabindranath Tagore, Nilratan Sirkar and Prafullachandra Ray. New ideas and innovations in that period lead the society into enlightenment.

The birth of modern science in India is mostly because of two great personalities – Acharya Jagadishchandra Bose and Acharya Prafullachandra Ray. Both of them are called 'Father of Modern Science in India'. Jagadishchandra laid the foundation of physics, biophysics and plant physiology research in our country whereas Prafullachandra became the initiator of chemical research and industries in India. One who has seen his portrait can easily realise the simplicity in his life-style. Gandhiji once commented, 'It is difficult to believe that the man in simple Indian dress wearing simple manners could possibly be a great scientist and professor'. But all of us know that he was not simply a scientist and a professor. He was a multi-faceted personality, a patriot, a social worker, a science-historian of international standing, and a tireless writer on science and society.

Prafullachandra's great grandfather earned a fabulous amount of wealth working as a Dewan under the collector of Krishnanagar and Jessore. Anandalal, grandfather of Prafullachandra sent his son Harishchandra, father of Prafullachandra, to Krishnanagar College for studying English, Sanskrit and Persian. But after the sudden demise of Anandalal, he was compelled to go home before the completion of his college education. Harischandra was a liberal man. He founded a middle school for boys and another school for girls in his village.

Prafullachandra was born on August 2, 1861 in Raruli-Katipara – a village of Jessore (now Khulna), Bangladesh. His mother was Bhubanmohini Devi. They were five brothers and two sisters – Jnanendrachandra, Nalinikanta, Prafullachandra, Purnachandra, Buddhadev, Indumati and Belamati. The family lost Buddhadev and Belamati when they were very young.

Prafullachandra started his education in his village. He studied there up to the age of nine and then came to Kolkata in 1870 for further education. They got a rented house (132, Amherst Street) where Harishchandra's family lived for a decade. Eldest Jnanendrachandra took admission in Hindu School whereas Nalinikanta and Prafullachandra got admission in Hare School. Prafullachandra suddenly fell ill and had to return to his own village for recovery. He could not attend school for one and a half years. During that period, Prafullachandra studied lot of books from his family's library. His basic interest was in history and language. Once he stated that he became a chemist by mistake, though it is difficult to know whether Prafullachandra made the statement in a serious mood.

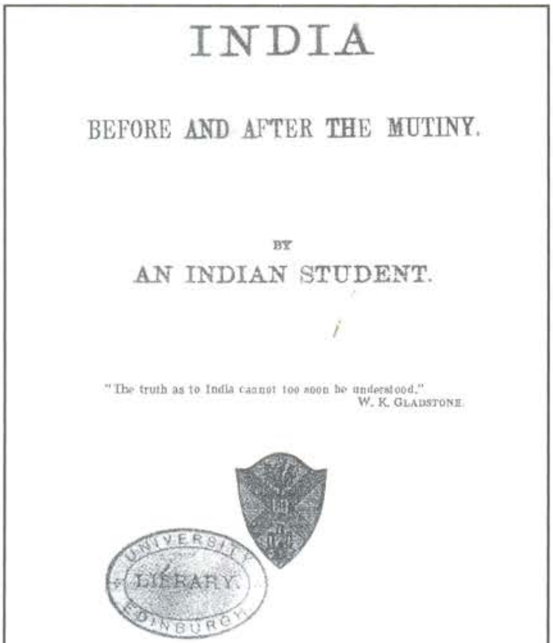
Fig. 1. Acharya Prafulla Chandra Ray (1861 - 1944)

After one and a half years, Prafullachandra returned to Kolkata and took admission in Albert School, a new school founded by Keshabchandra Sen. Prafullachandra had a desire to go back to Hare school but the teachers of Albert school did not like to miss a boy like Prafullachandra and kept him in the same school.

Prafullachandra passed the entrance examination in 1879 in first division. He then joined the Metropolitan Institution (now Vidyasagar College) and passed first arts (F.A.) examination in 1881 in second division. Metropolitan Institution did not have chemistry classes, so Prafullachandra during his B.A. classes used to attend the chemistry classes in Presidency Collage. He was much influenced by the teaching of Alexander Pedler (who later became Vice-Chancellor of the University of Calcutta). During his B.A. studentship, Prafullachandra appeared for Gilchrist Scholarship and got it. In 1882, he went to Edinburgh University. Alexander Crum Brown – an internationally known chemist and also a man of multiple culture - was

Prafullachandra's most favourite teacher. Prafullachandra passed B.Sc. in 1885 and became a D.Sc in inorganic chemistry in 1887. He did his work on conjugated sulphates of the Cu-Mg group which was published in 1888. Prafullachandra won the prestigious 'Hope Prize' and continued his research for one more year. During that time he was the Vice-President of Edinburgh Chemical Society. He returned to Kolkata in August 1889.

Here one important episode during his student life in Edinburgh should be mentiond. Prafullachandra participated in a competition to write an essay on 'India before and after the Mutiny'. He was exceedingly upright, courageous in his conclusions and criticized the British rule in India. That a 'native' student, 24-25 years old, Prafullachandra, could write such an essay, showed the potential of a historian in him. Let us cite few lines from the essay. 'It is forgotten that at the time when a queen of England was flinging into flames and hurling into dungeons those of her own subjects who had the misfortune to differ from her on dogmatic niceties, the great Mogul Akbar had proclaimed the principles of universal tolerance, had invited the molvi, the pandit, the rabbi, and the missionary to his court, and had held philosophical disquisitions with them on the merits of their various religions'.



INDIA

BEFORE AND AFTER THE MUTINY.

BY
AN INDIAN STUDENT.

"The truth as to India cannot too soon be understood."
W. K. GLADSTONE.

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Fig. 2 Cover page of the book 'India Before and After the Mutiny (1885).

Coming back from England after one year, Prafullachandra got appointment in Presidency College, Kolkata as a temporary Assistant Professor of Chemistry which he joined in July 1889. It was the same year when Alexandar Pedler was elected a fellow of the Royal Society, London. Chemistry teaching in India in the last decade of nineteenth century was only beginning. Historically the teaching of chemistry as a subject started at the Medical College after it was established in 1835. There was also a post of 'Chief Chemical Examiner' there. Chunilal Bose, who was also born in 1861, was a close friend of Prafullachandra and became the first Indian Chief Chemical Examiner. But proper teaching in chemistry started later, only after Alexander Pedler joined Presidency College in 1873. Prof. Pedler first published papers in chemistry in the *Journal of Chemical Society*, London and also in the *Journal of the Asiatic Society of Bengal*.

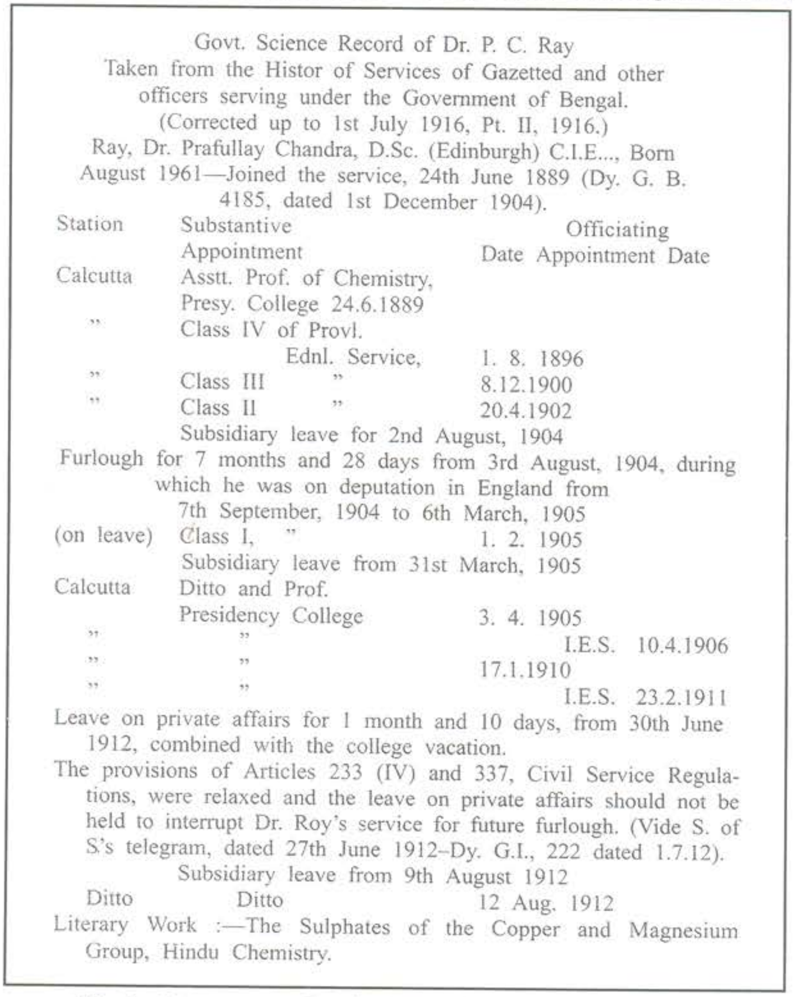
Jagadishchandra in physics and Prafullachandra in chemistry – two doyens of science were then working in Presidency College. Both of them had to overcome a number of hurdles to pursue their research. Jagadishchandra joined Presidency College in 1885, but he got his first publication during 1895, after a gap of one decade. Many readers may not believe that Jagadishchandra started his research in a room of 24 sq. ft. (about 2.2 sq.m) only. Similarly Prafullachandra joined the college in 1889 but got his first publication in the *Journal of Asiatic Society of Bengal* in 1894.

In 1890, Prafullachandra rented a house at 91, Upper Circular Road (now Acharya Prafullachandra Road) which is closest to University College of Science (92, Upper Circular Road) and the residence of Jagadishchandra Bose was at 93, Upper Circular Road. Prafullachandra started his research on the analysis of oil foods such as ghee, mustard oil and published his first paper (in India) in 1894. From 1894 to 1903, he published a total of 19 papers. All the papers were solely authored by him. Beside teaching and research, Prafullachandra also initiated a venture for preparing a number of chemical products so that India one day might be industrially self-reliant. The Bengal Chemical and Pharmaceutical Works (BCPW) took the shape from that venture. In fact BCPW was born in 1892 but it was declared a public limited company in 1902. Prafullachandra spent 27 years (1889-1916) in Presidency College. His influence as a teacher was boundless. A number of great Indian scientists of next generation such as Meghnad Saha, Satyendranath Bose, Jnanchandra Ghosh. Jnanendranath Mukhopadhyaya, Nilratan Dhar, Nikhilranjan Sen, Bireshchandra Guha were his beloved disciples. In the span of 27 years in Presidency College, Prafullachandra published a total of 87 papers, some as a single author and some with his research students.

Among the co-workers, Prafullachandra had the highest number of publications with Jitendranath Rakshit. Jitendranath failed in B.Sc. Examination and decided to go without the degree, but Prafullachandra appreciated his skill very much. At the beginning of his career, Prafullachandra had an intention to find out one or two new elements from Indian minerals. However, the attempt was not successful. But there came a turning point when he was performing gas analysis. In the process of purifying an impure sample of mercury, he discovered the formation of mercurous nitrite. In his paper in the *Journal of the Asiatic Society of Bengal*, Prafullachandra wrote: 'Having recently had the occasion to prepare mercurous nitrite in quantity by the action of dilute nitric acid in the cold on mercury, I was rather struck by the appearance of a yellow crystalline deposit. At first sight, it was taken to be a basic salt, but the formation of such a salt in a strongly acid solution was contrary to ordinary experience. A preliminary test proved it, however, to be at once a mercurous salt as well as a nitrite. The interesting compound promised thus amply to repay an investigation'. (1896)

Commenting on the paper, the journal 'Nature', wrote '*The Journal of the Asiatic Society* can scarcely be said to have a place in our chemical libraries; the current number, however, contains a paper by Dr. P. C. Ray of the Presidency College, Calcutta on mercurous nitrite that is worthy to note. During a preparation of mercurous nitrate by the action of nitric acid (dilute) in the cold on mercury, yellow crystals are deposited, which upon examination, proved to be mercurous nitrite (Nature, 1896). Prafullachandra was introduced in the world of chemists as 'Master of nitrites'.

After working from 1889 to 1900 alone, he finally got permission to have a research student. Prafullachandra mostly worked on problems of inorganic chemistry. But he also did some work on different topics of organic as well as physical chemistry.



Govt. Science Record of Dr. P. C. Ray
Taken from the Histor of Services of Gazetted and other
officers serving under the Government of Bengal.
(Corrected up to 1st July 1916, Pt. II, 1916.)
Ray, Dr. Prafullay Chandra, D.Sc. (Edinburgh) C.I.E..., Born
August 1961—Joined the service, 24th June 1889 (Dy. G. B.
4185, dated 1st December 1904).

Station	Substantive Appointment	Date	Officiating Appointment	Date
Calcutta	Asstt. Prof. of Chemistry, Presy. College 24.6.1889			
"	Class IV of Provl. Ednl. Service,	1. 8. 1896		
"	Class III "	8.12.1900		
"	Class II "	20.4.1902		
	Subsidiary leave for 2nd August, 1904			
Furlough for 7 months and 28 days from 3rd August, 1904, during which he was on deputation in England from 7th September, 1904 to 6th March, 1905				
(on leave)	Class I, "	1. 2. 1905		
	Subsidiary leave from 31st March, 1905			
Calcutta	Ditto and Prof. Presidency College	3. 4. 1905		
"	"		I.E.S.	10.4.1906
"	"	17.1.1910		
"	"		I.E.S.	23.2.1911

Leave on private affairs for 1 month and 10 days, from 30th June 1912, combined with the college vacation.

The provisions of Articles 233 (IV) and 337, Civil Service Regulations, were relaxed and the leave on private affairs should not be held to interrupt Dr. Roy's service for future furlough. (Vide S. of S.'s telegram, dated 27th June 1912–Dy. G.I., 222 dated 1.7.12).

Subsidiary leave from 9th August 1912
Ditto Ditto 12 Aug. 1912

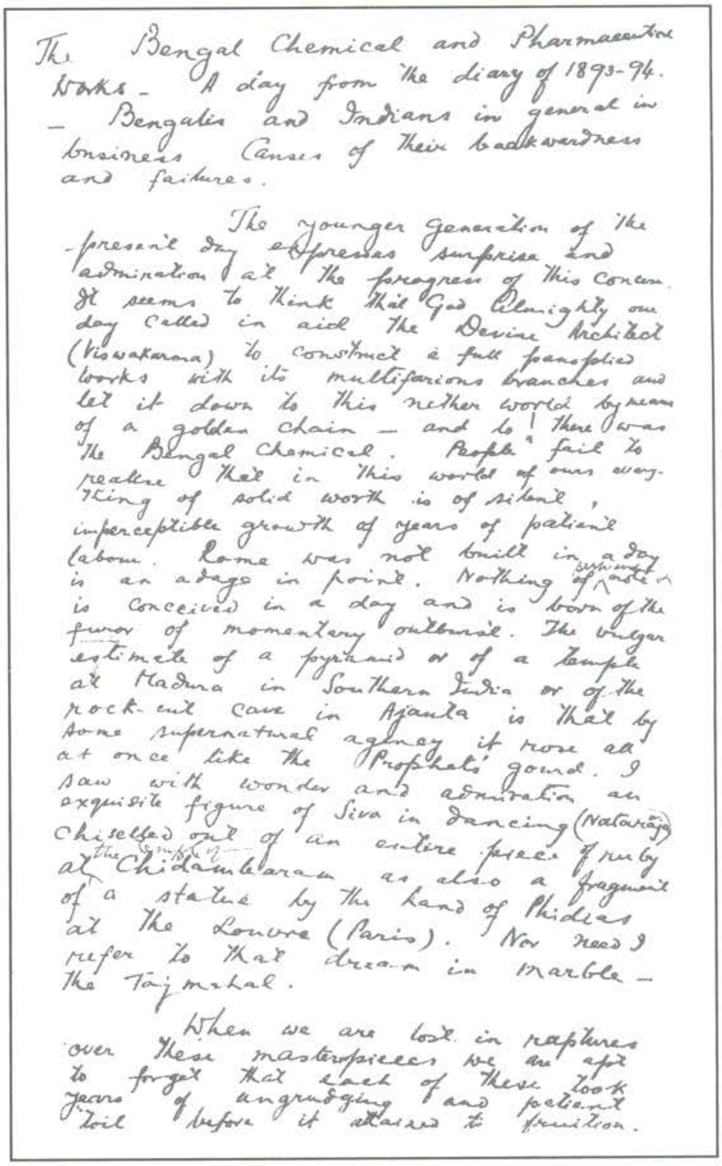
Literary Work :—The Sulphates of the Copper and Magnesium Group, Hindu Chemistry.

Fig. 3. Government Service Record of Acharya Prafullachandra Ray.

Prafullachandra took his retirement from Presidency College after the age of 55 years and joined the University of Calcutta on the request of the Vice-Chancellor Sir Asutosh Mukhopadhyay. Prafullachandra served the University as Sir Taraknath Palit Professor from 1917 to 1936.

During that period, a large number of students worked with him. A total of 72 papers were published. Most of his publications were in the *Journal of the Chemical Society*, London. Prafullachandra and some of his senior associates were feeling the need of an Indian chemical journal. As a result, Indian Chemical Society was established in 1924. Prafullachandra became the founder-president of the Society and most of his papers, there after, were published in 'Journal of Indian Chemical Society'.

After one decade of the establishment of Indian Chemical Society, another organisation was instituted by Acharya Prafullachandra and his most-beloved disciple Meghnad Saha. The name of the organiation was Indian Science News Association (ISNA) which was established in 1935. Its objective was to disseminate science news as well as the reflection of the community of Indian scientists and thinkers for public understanding of science and culture together. The founder-president of ISNA was Acharya Prafullachandra. Prof. Meghnad Saha and Prof. Bidhu Bhusan Ray became the founder-secretaries of the Association.



The Bengal Chemical and Pharmaceutical Works. – A day from the diary of 1893-94. – Bengalis and Indians in general in business. Causes of their backwardness and failures.

The younger generation of the present day expresses surprise and admiration at the progress of this concern. It seems to think that God Almighty one day called in aid the Devine Architect (Viswakarma) to construct a full fledged works with its multifarious branches and let it down to this nether world by means of a golden chain – and lo! there was the Bengal Chemical. People fail to realise that in this world of ours everything of solid worth is of silent, imperceptible growth of years of patient labour. Rome was not built in a day is an adage in point. Nothing of [illegible] note is conceived in a day and is born of the furor of momentary outburst. The vulgar estimate of a pyramid or of a temple at Madura in Southern India or of the rock-cut cave in Ajanta is that by some supernatural agency it rose all at once like the 'Prophets' gourd. I saw with wonder and admiration an exquisite figure of Siva in dancing (Natarāja) chiselled out of an entire piece of ruby at the temple Chidambaram as also a fragment of a statue by the hand of Phidias at the Louvre (Paris). Nor need I refer to that dream in marble – the Taj mahal.

When we are lost in raptures over these masterpieces we are apt to forget that each of these took years of ungrudging and patient toil before it attained to fruition.

Fig. 4. A page of the manuscript of 'Life and Experiences of a Bengali Chemist'.

Prafullachandra was against ivory-tower scientists. His involvement in all types of social issues was very transparent and encouraging.

Prafullachandra never forgot to come forward when there were floods or famines in Bengal. He had a very strong sympathy for the revolutionaries. He even contributed for secret purchase of arms for the freedom fighters. During the movement against Rowlatt Act, Prafullachandra made a memorable statement: 'There are occasions when a scientist should leave his test tube to attend to the call of the country'. The scientist donated almost all his earnings for the welfare of distressed and downtrodden people. One of his biographers wrote :

'He never took any honorarium, remuneration or Director's allowance from B.C.P.W. – all were given away directly or through trusts. The salary of Palit Professor from 1922-1936 was not drawn but donated for the improvement of chemistry department of Calcutta University'. However, he had a very strong opinion that university had been converted to a factory for mass production of graduates.

Prafullachandra was awarded D.Sc. from Durham University in 1912. Long later, he was conferred D.Sc. by the university of Dacca and the University of Banaras. In 1922, Prafullachandra was elected the general president of the Indian Science Congress.

The life-sketch of Prafullachandra could never be complete without mentioning about his book *A History of Hindu Chemistry*. Prafullachandra wrote the first volume of his book in 1902 and 2nd volume in 1909.

'Knowledge in the fields of philosophy and mathematics including astronomy, arithmatic, algebra, trigonometry and geometry and medicine has received some share of attention. One branch has, however, up till this time, remained entirely neglected viz. Chemistry ....complex and technical nature repelled the investigators'.

We quote here a words of appreciation in a letter from Marcellin Berthelot (1827-1907) to Acharya Prafullachandra after receiving a copy of A History of Hindu Chemistry, vol.1.

'I have received your chemical researches which are highly interesting and I have seen specially with pleasure how science with its universal and impersonal character is equally cultivated by all civilised peoples of Asia as well as Europe and America'.

It should be noted that Prafullachandra dedicated the second volume to the memory of Professor Marcellin Berthelot.

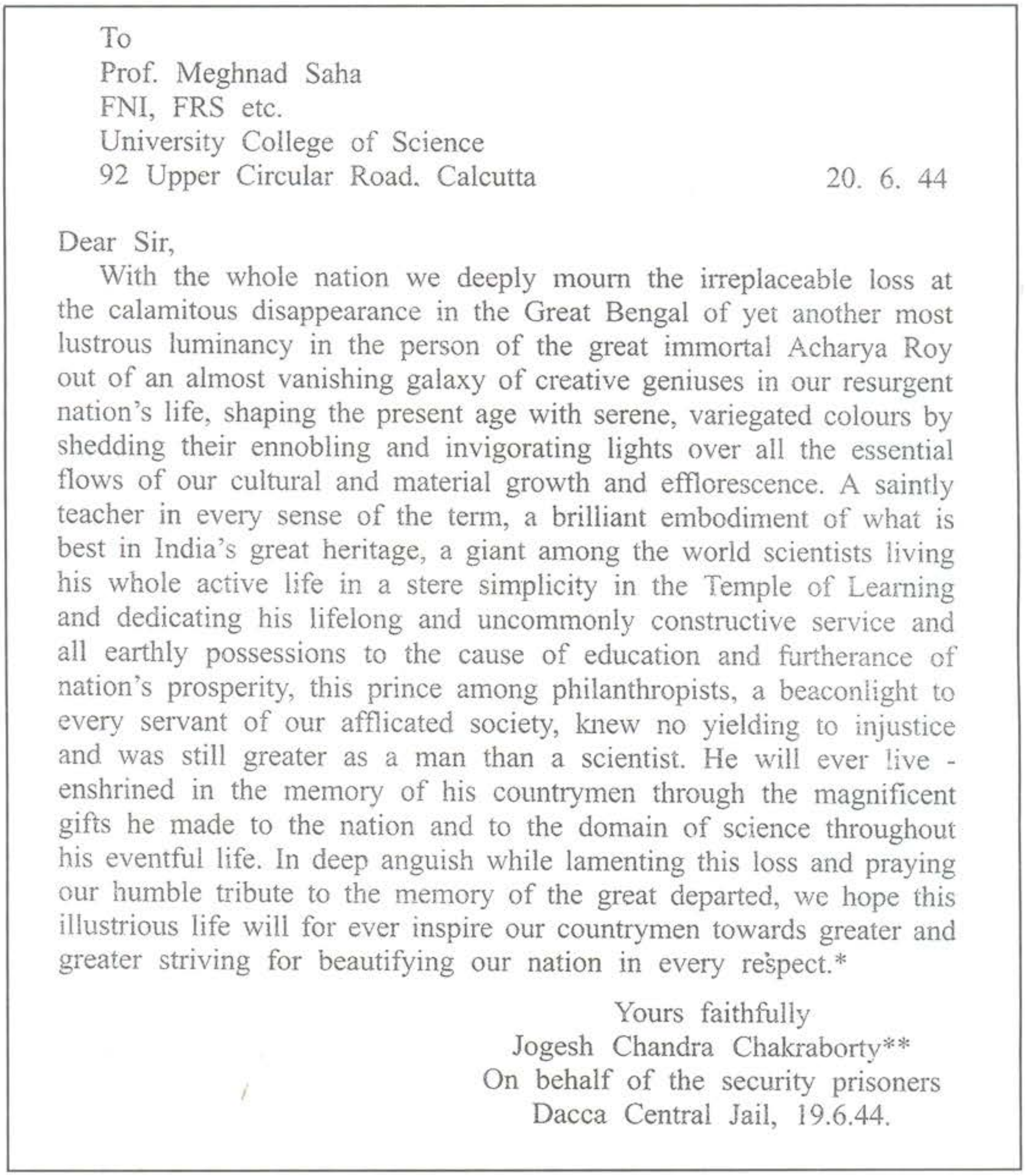
Prafullachandra straightway mentioned that the emergence and decline of science depend on the laws of society but not on the laws of science. He wrote history which had more analytical than information bias. He firmly rejected the 'internalist hypothesis' (i.e. science constructs science, no impact of society) of science. According to him, the Vedanta philosophy modified and expanded by Samkara is responsible for bringing physical science into disrepute. The book was highly appreciated by *Nature*. It has been a labour of love……the great value of the results of his patient and laborious researches will be fully appreciated by all students of history of chemistry'.

(*Nature*, July 21, 1910)

According to Prafullachandra, cohesion of Intellectual labour and physical labour results the advancement of our society but when there is a conflict, the civilisation collapses. A number of old civilisations were ruined for this reason. What was advocated by Prafullachandra that had also been supported by Joseph Needham for Chinese civilisation and Benjamin Farrington for Greek civilisation. The book was out of print for a long time and got published in 2002 as a 'centenary edition' with a humble note of regards by the present author. The most important chapter of the book was 'Knowledge of technical arts and the decline of scientific spirit' where Prafullachandra clearly said, 'The intellectual portion of the community being thus withdrawn from active participation in the arts, the how and why of phenomena - the co-ordination of cause and effect - were lost sight of and the spirit of enquiry gradually died out among a nation naturally prone to speculation and metaphysical subtleties and India for once bade adieu to experimental and inductive sciences. Her soil was rendered morally unfit for the birth of a Boyle, a Des Cartes or a Newton and her very name was all but expunged from the map of scientific world'.

In the year 1997, the University of Calcutta established 'Acharya P. C. Ray Museum' in the room of the department of chemistry where he used to work. The museum contains his personal belongings, his collection of books (with personal comments), manuscripts and reprints of his articles and also a good number of correspondences. Prafullachandra was an expert on Shakespeare. His *The Shakespearean Puzzle*, is a brilliant collection of articles. There were a number of books on Shakespeare in his personal library.

The end of this great life came on June 16, 1944. Prafullachandra died in his room in the college of science, Calcutta University, surrounded by his students and admirers.



To
Prof. Meghnad Saha
FNI, FRS etc.
University College of Science
92 Upper Circular Road. Calcutta 20. 6. 44

Dear Sir,

With the whole nation we deeply mourn the irreplaceable loss at the calamitous disappearance in the Great Bengal of yet another most lustrous luminancy in the person of the great immortal Acharya Roy out of an almost vanishing galaxy of creative geniuses in our resurgent nation's life, shaping the present age with serene, variegated colours by shedding their ennobling and invigorating lights over all the essential flows of our cultural and material growth and efflorescence. A saintly teacher in every sense of the term, a brilliant embodiment of what is best in India's great heritage, a giant among the world scientists living his whole active life in a stere simplicity in the Temple of Learning and dedicating his lifelong and uncommonly constructive service and all earthly possessions to the cause of education and furtherance of nation's prosperity, this prince among philanthropists, a beaconlight to every servant of our afflicated society, knew no yielding to injustice and was still greater as a man than a scientist. He will ever live - enshrined in the memory of his countrymen through the magnificent gifts he made to the nation and to the domain of science throughout his eventful life. In deep anguish while lamenting this loss and praying our humble tribute to the memory of the great departed, we hope this illustrious life will for ever inspire our countrymen towards greater and greater striving for beautifying our nation in every respect.*

Yours faithfully
Jogesh Chandra Chakraborty**
On behalf of the security prisoners
Dacca Central Jail, 19.6.44.

Fig. 5. Condolence resolution of the security prisinors of Dacca Central Jail (19.6.44) after the death of Acharya Prafullachandra Ray (16.6.44).

Prof. Syamal Chakrabarti of Department of Chemistry, University of Calcutta is a noted popular science writer and the recipient of 'Satyendranath Bose Award' and 'Rabindra Puraskar' for his contribution to science literature.

Remembering Homi Jehangir Bhabha

Mayank Vahia

Homi Jehangir Bhabha (October 30, 1909 – January 24, 1966) defined India's post independence identity more than any other scientist has done. He not only excelled in research himself, but in fact ensured that the nation as a whole matured as a country that could be at the forefront of world research, a dream that we are just beginning to achieve. He laid out and defined the foundation of post independence research in India more than anyone else.

Early Life and Education

Bhabha was born in a prominent family, through which he was related to Dinshaw Maneckji Petit, Muhammad Ali Jinnah, Homi K Bhabha and Dorab Tata. He obtained his early education in the Cathedral Grammar School (which is now known as Cathedral and John Connon School) in Mumbai. From his early days however, Homi was exposed not only to science, but equally with art and music and human values, all of which formed the core of his personality that drove him and those around him to not only excel in their chosen field but also to appreciate excellence elsewhere.

After completing his schooling, at the age of 15, he joined the Royan Institute of Science. Following the pattern of the time, his father decided that he should pursue his higher education in UK and hence Bhabha joined the Caius College in Cambridge University, UK.

When he left India, the country was already getting ready for momentous changes as the momentum of the struggle for freedom from the British rule was picking up. His father felt that it would be good if young Bhabha became an engineer, but Bhabha had other plans. He wanted to pursue physics to the exclusion of all else. His father would agree with him provided he proved that he could be an excellent engineer if he chose to be. He took up Mechanical Engineering Tripos (an equivalent of Honours bachelor's degree) and after excelling in it, changed over to physics. This apparently stubborn standoff between the father and the son in fact would auger well for the nation, for Bhabha would eventually be called upon not only to excel in science but also engineer the country's scientific needs for the future.

Scientific Achievements

After the Engineering Tripos, Bhabha did one more Tripos in Mathematics under Paul Dirac. He worked at the Cavendish Laboratory while working towards his doctorate in theoretical physics under R. H. Fowler. Bhabha was fascinated by quantum mechanics that had been the core of Paul Dirac's work and equally by the work of R. H. Fowler on the electron band gaps and thermodynamics of systems. In 1936, Bhabha worked with Walter Heitler of Wills Physical Laboratory at Bristol and developed the now famous Bhabha-Heitler Cascade Theory of Cosmic Ray showers. The results were published in 'Nature'. Bhabha found a permanent place in the history of physics. With a special Rouse Bell travelling studentship, Bhabha went on to work with Niels Bhor in Copenhagen, Wolfgang Pauli in Zurich, Enrico Fermi in Rome and Hans Kramers in Utrecht.

Pencil sketch of Homi Bhabha.

In 1939, when Bhabha was vacationing in India, the second World War broke out. He chose to remain in India until the war ended. He accepted a position offered by C V Raman at the Indian Institute of Science, Bangalore. Here he established the Cosmic Ray Research Unit.

Homi Bhabha and Neils Bhor.

However, the mood in the nation was changing. The nation was beginning to sense that independence from the British was round the corner and the leaders of the nation had to start preparing the future path of the Nation. A close friend of Jawaharlal Nehru, Bhabha soon immersed himself in chalking out the path of India's re-entry into the great world of science and technology.

Institution Building

In 1943 Bhabha wrote a letter to the Sir Dorabjee Tata Trust requesting for funding to start an institute of research in India: "an embryo from which I hope to build up in the course of time a school of physics comparable to the best anywhere". The Tata Trust readily granted his request and the Tata Institute of Fundamental Research (TIFR) was established on June 1, 1945 at the Indian Institute of Science campus in Bangalore. He soon shifted back to Mumbai and gave firm foundations to the institute in Mumbai. He requested his aunt to donate her bungalow at Kenilworth to the Institute and the aunt's house became the Institute and the gardener's bungalow became the Director's bungalow. However it was soon realised that under the leadership of Bhabha, the institute would truly meet its promise and hence needed a support far greater than what the Tata Trust could provide. Therefore TIFR entered into a tripartite agreement with Government of Bombay, Government of India and TIFR became the National Centre of the Government of India in Nuclear Sciences and Mathematics under an Act of the Parliament. This arrangement continues even today. Bhabha set up the structure, administration and activities of TIFR in such a way that the scientists continue to enjoy maximum freedom, even as there is sufficient support to allow them to continue their work unhindered. The model of administration he set up continues to be studied and followed more than 60 years after it was set up.

Vision

However, his vision continued to be broad as ever and he soon recognised in Vikram Sarabhai another stalwart who could lead India's quest for scientific progress. Even as Bhabha himself set up the Atomic Energy activity in India, he ably supported Sarabhai in setting up India's space programme. In 1948 he started the Atomic Energy Commission under which he set up India's first experimental nuclear reactors in the outskirts of Mumbai. Later on, this setup would be renamed as the Bhabha Atomic Research Centre and would be the foundation of India's nuclear energy programme.

The philosophy behind setting up these institutions was novel, to say the least. For TIFR, Bhabha never listed out the topics in which he wanted the research done. Instead he concentrated on identifying excellent people and then letting them grow on their own pursuing their instinct about the line of investigation they wanted to follow. He went to the extent that when he found an excellent biologist he even offered him a position in an institute that was officially meant for physics. This is the philosophy that TIFR follows even today where great care is taken in selecting scientists but once selected, they are allowed to pursue their personal query. This philosophy has meant that TIFR has excelled in fields of research as varied as research in cancer of the mouth induced by tobacco usage, molecular biology and genetics, chemical physics, large molecule studies and nuclear physics, atomic physics, nano sciences and astrophysics. Essentially, this has provided the country with experts in a wide variety of subjects even as it has given some excellent scientists opportunities to do research on a subject to their choice. The only criterion of judging the work is international scholarship in this field that generally goes under the name of blue sky research. While such a research does not necessarily produce applicable research, it is highly innovative and pushes technology to its extreme resulting in new insights into the working nature.

In contrast, the Atomic Energy Commission was set up with the express task of designing and running nuclear reactors and allied technologies. This focus on technology development that has proven to be the backbone of India's march into modern fields of science and technology, proved crucial for India's energy and defence needs.

A Multi-faceted Personality

Another unusual features of Bhabha's style was his synthesis of science and art. While the campuses of BARC and TIFR are designed with utilitarian compactness, their artistic and aesthetically pleasing

Painting by Homi Bhabha

design layout cannot be denied. The buildings inspsire both, a soothing thought and creativity. Equally interestingly, the buildings have been endowed with the country's largest collection of modern Indian paintings that he purchased from artists who were unknown at that time but rank amongst the most famous names in Indian art today. They include, M F Hussain, Kishan Khanna, K H Ara, Sabbawalla, Langhimer and others.

However, Bhabha was a world citizen. His dreams of using nuclear energy for the salvation of mankind by providing cheap and reliable energy extended beyond the needs of the citizen of India. In the 1950s, Bhabha represented India in International Atomic Energy Forums where he worked vigorously for peaceful uses of nuclear energy and served as President of the first United Nations Conference on the Peaceful uses of Atomic Energy in Geneva, Switzerland in 1955.

Even while working at the cutting edge of science and science policy, Bhabha was a keen science communicator and made several excellent films on various aspects of science and daily life with the Films Division of India which still make delightful viewing.

Honours & Awards

Amongst his many recognitions, he was elected a Fellow of the Royal Society of London in 1941 as a recognition to his contributions to the field of cosmic rays, elementary particles and quantum mechanics. From 1960 to 1963, he was the President of the International Union of Pure and Applied Physics, the highest professional body of physicists in the world. He was awarded Padma Bhushan by Government of India in 1954. He later served as the member of the Indian Cabinet's Scientific Advisory Committee and set up the Indian National Committee for Space Research with Vikram Sarabhai.

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Tagore's Cosmic Scepticism and Modern Science

Ashish Lahiri

Abstract

The swing between the sense of the mysterious sublime and that of the comprehensible universe characterises Tagore's coming to terms with modern science. There are three distinct stages. At the first stage he is a diligent, if capricious, student of science – one for whom science and poetry belong to two great but mutually exclusive worlds. The essay Āmār Jagat (My World, 1914) represents the culmination of this phase. Reductionist science, he seems to say, has no business to meddle in the affairs of poetry. The second stage, however, is characterised by a drastic change of perception. 'Modern science analyses reality with a detached mind; modern poetry should also do the same, for that is what is eternally modern.' He even wonders why higher mathematics should not be the subject of poetry. In 1928 he told Heisenberg that in the Isha Upanishad there is a strand of thought that supports Heisenberg's Principle of Indeterminacy. In 1930 he debated with Einstein whether there was any reality independent of the human mind. In the final phase, epitomised by the book Visva-Parichay (1937), he arrives at an open-ended, non-theological and non-dogmatic view of reality. One would like to characterise this approach as 'cosmic scepticism'.

At the early age of 12, after his *upanayana* (the sacred thread ceremony, a rite reserved for Brahmins), Rabindranath's father Debendranath ritualistically introduced him to the *gāyatrī mantra*[1]. 'The splendid cadence and intonation of this Vedic verse appealed strongly to his feeling for rhythm and his sense of the mysterious sublime. The *gayatri* remained his lifelong companion and he continued to find in it a source of contemplative insight and strength long after he had discarded the sacred thread'.[2]

Simultaneously, thanks to the rigorous coaching of his house tutors, he had already learnt that there are certain laws of nature in accordance with which nature works and which are 'testable' (to use a phrase from Karl Popper). That was how the seed of the swing between the sense of the mysterious sublime and that of the comprehensible universe was sown in his mind, wonder being the common factor linking them.

In the introduction to his book on modern physics and cosmology, *Viśvaparicay* (An Account of the Universe, 1937), dedicated to the physicist Satyendranath Bose (of Boson fame), Tagore wrote[3]:

> ... Right from childhood, my craving for the taste (*rasa)* of science knew no bounds. I believe I was nine or ten at the time, when Mr. Sitanath Datta [Ghosh] would sometimes drop in on a Sunday. I now know that his stock was not big, but when he explained a simple theory or two of science with illustration, my mind would fill with wonder. I still remember that he would put a beaker of water on heat, and pouring sawdust into it showed how the hot water, being lighter, streamed upwards and the cold water, being heavier, moved downwards, and that was how the entire mass of water heated up. I still remember the thrill of discovering a solid mass of water dividing into two streams at the same time.

This is a typical example of what he would later describe as seeking 'pleasure in the analytical view of objective reality'. What stirred him as a boy was the realisation that the heart of something apparently so quiet as a beaker of water could contain such tremendous turbulence. He was convinced of the restricted nature of the one-dimensional world of our common sense experience, and could feel that in order to get at the true nature of things, you have to destabilise them and change the 'given' state. Thus scepticism and not blind acquiescence with passive reality, is the key to knowing nature. You have to confront and not merely worship nature as the giver of all that is, as the *gāyatrī* would prompt you to do.

Einstein and King Pravāhaṇa

A little diversion may be rewarding here. One recalls a similar, but far more intense, encounter of Einstein's who 'experienced a miracle ... as a child of four or five when [his] father showed [him] a compass.' Quoting Einstein's sister, his biographer Abraham Pais informs us that 'It excited the boy so much that "he trembled and grew cold. ... There had to be something behind objects that lay deeply hidden."...' The interesting point, however, is that for the rest of his life Einstein believed that 'the development of [our] world of thought is in a certain sense a flight away from the miraculous'.[4] The phenomena only *appeared* to be miraculous, in reality they were not. They were wonderful, even awe-inspiring, but not miraculous. Miracles were merely reflections of one's ignorance about the myriad laws of nature or of one's commitment to the irrational (that was Spinoza speaking!). Like Rabindranath, Einstein too was drawn to institutional religion in his childhood, but at the age of twelve, with his first formal introduction to organized science, he for ever gave up that path. In later life what he eulogised as 'Cosmic Religion' had nothing to do with religion *per se*. Einstein once remarked, 'What really interests me is whether God had any choice in the creation of the world.' The very wording of the question showed that he had no need for a conventional, omnipotent God. Steven Weinberg rightly points out that 'Einstein's religion was so vague that I suspect that he meant this metaphorically…'[5] He literally carved out his mind in the immortal quote: 'Subtle is the Lord, but not malicious.' The 'Lord', i.e. Nature, would not reveal His mysteries at one go; but eventually He will, in small hiccups, in an exasperatingly tantalising process. Einstein was a realist *par excellence*. He believed in the real existence of the world and the complete 'knowability' of the world, however tough the task.

Not so with Tagore. Philosophically he was a dualist, not a realist. For the greater part of his life, he had been a believer in religion. He was not a reductionist trying to understand nature in terms of its basic constituents; he was a holistic synthesiser trying to fathom the meaning of the phenomenal universe:

āndhār rāte œklā pāgol jāy kende
bale śudhu, bujhiye de, bujhiye de, bujhiye de

In dark night the desolate man goes crying
in frenzy, unveil, oh unveil the mystery.

For him there was always something transcendental, something beyond the reach of human experience. It is the illimitable, he said, that continually spurs on physical science to search for new frontiers. He would fondly refer to King Pravāhaṇa of *Chāndogya Upanishad* (1:8:8) to drive home the point:

> If man would ever stoop to agree that there was an absolute limit, then his physical science would have dropped anchor and stopped moving long ago. Scientists had once claimed that they had pealed off all the layers of the fundamental elements of the physical world: so absolute was the pealing that the elements were not analysable any further. But see what has happened to that claim. Seated in the heart of things, King Pravāhaṇa goes on propelling all human enquiries further and further beyond every limit.[7]

Of Sawdust and Stars

Let us now come back to our original story. A few years after the child Rabindranath had learnt the theory of convection of heat from his house tutor, he accompanied his father

> to Dalhousie in the Himalayas. … He (Debendranath) would acquaint me with the stars and the planets. He would go further and tell me about the planets' orbital distances from the sun and the duration of each planetary year. I used to take notes. Based on those I penned an immature article. I wrote because I had savoured the taste – this was my first-ever biggish article and its content was scientific information.[8]

Thrill' and 'taste' are the keywords at this stage. What did the boy taste? What thrilled him? It is easy to reconstruct that he had sensed an isometric unity between the circulating stream of sawdust in the beaker of hot water and the celestial objects moving about in empty space. He was awestruck by the fact that the sawdust, the water, the fire of the burner and the bright objects millions of light years away should obey the same set of physical laws. This is not philosophy. This is something one feels in one's bones, something that could stir one into poetry, into music. How strange that these insignificant, puny, helpless creatures that call themselves *homo sapiens* should be tied to the immeasurably vast universe through the bond of a *single* set of interconnected laws! And science is all about finding out and mastering those laws. This appreciation itself is a wonder, that itself gives a taste of the infinite and the taste of infinity gives one the assurance of a cosmic shelter. What is significant is that Rabindranath got a first glimpse of that sanctuary through science at a very early age.

Later he would explain the emergence of life in these terms: 'Then came a time when life was brought into the arena in the tiniest little monocycle of a cell.' He went on to elucidate how that tiny cell of life could add value to existence by 'overcoming the *obstructive inertia of Nature by obeying Nature's law*'.[9] You have only to break the obstructive inertia of nature, for instance by heating water, and then you come to know about the laws of nature which you cannot but obey, being a part of nature yourself. It is not for you that nature works; it has its own ways. It is for you to discover those hidden, often camouflaged laws, and that is where the whole humanity depends on science. It is this emphasis on the laws of nature, to be discovered by following the scientific method, that distinguishes Tagore from most of the other idealistic artists and thinkers of modern India.

On the strictly philosophical plane too, Tagore conceptualises the holistic integration working through the apparently separate principles of nature. This integration he calls 'a comradeship of creative co-ordination with the entire physical universe.' Here is an interesting example. 'Take, for instance, a piece of coal. When we pursue the fact of it to its ultimate composition, substance, which seemingly is the most stable element in it, vanishes in centres of revolving forces. These … can further be analysed into a certain number of protons and electrons. Yet these electrical facts are what they are, not in their detachment, but in their interrelationship, and though possibly some day they themselves may be further analysed, nevertheless the pervasive truth of interrelation which is manifested in them will remain'.[10]

In a sense, it would not be an exaggeration to say that throughout his life, through all his creations, Rabindranath has given expression to this one wonder of comradeship, this one taste in many words, many tunes, many hues and many metres.

Mahāviśve, mahākāśe, mahākāla mājhe
āmi mānava ekākī bhrami vismaye

In immense space, in immense time, in an immense world,
I roam - Man, alone in wonder.

The fact that the atom and the sub-atomic particles are ever restless, and yet that ferment is incomprehensible to our common sense, never failed to amaze Rabindranath. That scientists could reconcile, explain and formulate such grossly contradictory notions is, for him, one of the greatest triumphs of *homo sapiens*, something that sets the species apart from animals. Talking of the celebrated particle-wave duality of light, he remarks,

> These contradictory notions lie beyond the realm of the common-sense language of human beings. Yet, human beings did not fight shy of diving deep into the sea of the incomprehensible. They did not even hesitate to call this stonewall an unceasing dance of electrical particles! They did not fear that they might have gone mad. … In fact, science has proved that human beings *are* a race of animals bemused in madness. Whatever they think they perceive is in reality the exact opposite of what it actually is. Animals are never so libellous about themselves.[11]

Once again, we find, more than the facts and the theories of science, he values the excitement, the wonder that flows from it. This gives him an easy route away from philosophy to creative art. He characterises the primeval dance of the atom as 'rebellious' and 'beautiful'. That life-breathing dance sensitises the 'inert world' into consciousness, causes absolute bliss to undulate in rhythms and tunes, through joy and sorrow. Not stability, nor unwavering stillness, but instability and rebelliousness are at the bottom of all creation.

Viśva-tanute aṇ ute aṇ ute kānpe nṛtyera chāyā

In all molecules of universe-body pulsates the shadow of this dance.

One would like to characterise this process as a creative internalisation of scientific scepticism.

Three Stages

In this process, there are three distinct stages. At the first stage he is a diligent, if capricious, student of science – one for whom science and poetry belong to two great but different worlds, mutually exclusive. We find him engaged in developing a scientific temper among the intelligentsia. It has recently been discovered that among other things he was familiar with the works of the famous French textbook writer Adolphe Ganot (1804-1887).[12] Ganot's physics textbooks had ruled European schools and undergraduate classes for more than five decades. All Bengali physics textbooks were modelled on Ganot's books till 1898. Tagore's acquaintance with Ganot is apparent from an enigmatic reference to Helmholtz and Ganot in the famous satirical poem *Unnatilakshan* ('Signs of Progress', included in his book of poems *Kalpanā*) written in 1900 where he mercilessly ridiculed the strong variety of the slavish pro-British Hindu revivalism that glorified every nauseous superstition in the name of science.

As the culmination of this stage, one might consider his delightful essay *Āmār Jagat* (My World), written in 1914, shortly after he had returned from a momentous tour of Europe and the USA. Here he records a mock debate between a poet and his scientist friend. He apparently accepts the superior position of science so far as knowing objective truths is concerned. He does not question the validity of such knowledge. One finds the patronising scientist almost patting the poet on the back. Presently the poet hits back, questioning the scientist about his methodology. When describing the apparently fixed stars, astronomy says, they only appear fixed, because you are looking at them from such a great distance. If you look at them from a sufficiently close distance, or can devise some mathematical substitute for such close observation, you will find that they are actually moving fast. Very fine; then how about the earth? The surface beneath your feet is obviously flat, then why do you say that the earth is actually round? Here your point is that if you looked at the earth from a distance, you would get a real picture of its true shape. Why these double standards? Why do you discount your immediate sense data in one case and accept them in the other? Heaping instance upon instance, drawn from the fields of physics, botany and psychology, Tagore himself arrives at the synthesis that both these viewpoints are necessary: he calls them the *near side* and the *far side* of the same thing. One may characterise these as the reductionist and the holistic approach respectively. In his typical Upanishad-honed fashion, he calls them the finite and the infinite. A complete mind, he asserts, has place for both. Indeed, only that mind is complete which can simultaneously comprehend the invisible ever-restless sub-atomic particles and an apparently solid nugget of iron, or the extensively porous leaf when looked under a microscope and the tightly shaped leaf seen by the naked eye. He generalises that the concepts of time, space, position, distance, nearness, movement, stillness, inside, outside – all have this dichotomy. He joyously quotes the famous lines from *Īsha Upanishad* to drive his point home: *tadejati tannaijati taddūre tadvantike* (It moves, it moves not; it is far, it is near).

From here, it is only a step to conclude that the poet need not feel shy when his feelings are apparently at variance with the ideas of the scientist. Poetry has a world of its own which is simply out of bounds for reductionist science. The point to note is that he is not against reductionist science *per se,* as long as it remains confined to the domain of science. Reductionist science, he seems to say, has no business to meddle in the affairs of poetry. Thus, in the end the patronising scientist gets a much-deserved rebuff from his poet friend.

Poetry and Mathematics

From this time onwards, we find in him a finer appreciation of the philosophical problems of science, as well as its relationship with the other creative aspects of man. At the culmination of this stage, he makes a surprising statement in 1932:

> If you ask me what pure modernism is, I would say it's looking at the world not with a subjective personal attachment, but with an objective clinical detachment. That is what constitutes a pure vision; that detached vision is bliss. Modern science analyses reality with a detached mind; modern poetry should also do the same, for that is what is eternally modern.[13]

It is 'surprising', because earlier he had accused modern (i.e. reductionist) science of intruding upon literature and thereby robbing it of its essential beauty, which resided in purely non-rational personal attachment. Literature, he said, was characterised essentially by its prejudices and caprices, which was in direct opposition to the impersonal, rational objectivity of science. He cites a beautiful example from his own *Chitrāngadā.* Arjuna is indulging in voyeurism, when he stealthily looks at young narcissistic Chitrāngadā undressing before bathing in a pond, rapt at the exquisiteness of her own form. Arjuna is excited and overwhelmed. This, Rabindranath appears to be saying, can be treated in two ways. One is the strictly Freudian interpretation, which is perfectly in order as science. However, the moment that interpretation interferes with and dominates over artistic presentation, it kills art. Tagore felt that Western literature of the modern period had fallen victim to just such an aggression from science. The extreme obsession of literature with the purely physical aspects of sex, which he saw as a 'nuisance', was a manifestation of this breakdown.[14]

Therefore, when he jumps from this position to its opposite and says that 'poetry should also do the same, for that is what is eternally modern', one is a little taken aback. However, he goes further:

> The mathematician no doubt engrosses himself in the profound symmetry permeating high-level mathematics, in the unity of forms. The fact of its orderliness is not only epistemic, it belongs also to the sphere of deep feeling: there you get pure bliss. It finds expression at the apex of knowledge where it is free of any utilitarian concern. There knowledge attains liberty. One naturally wonders why this has not been the subject of poetry. The reason, of course, is that its experience is esoteric, its access denied to the common person.

Thus, the poet confidently says, there is no intrinsic impediment to high mathematics being the subject of poetry! What a change from the position that science was poking its ugly nose in the delicate affairs of poetry!

Tagore and Heisenberg: Scepticism and Uncertainty

The third phase is marked by some original insights into philosophy of science. His 1930 'conversation' with Einstein is now staple food for philosophers of quantum mechanics. Here, however, we shall recount the less discussed 1928 tête-à-tête between Tagore and Werner Heisenberg (1901-1971).

The basic idea of Heisenberg's 'Uncertainty Principle' (also known as 'Indeterminacy Principle') is: 'it is impossible to determine with accuracy both the position and the momentum (e.g., an electron) simultaneously. The more accurately the position is known, the less accurately can the momentum be determined. It appears to undermine the "common sense" view of cause and effect, at least on the atomic scale. How can two consecutive observations of the same particle be distinguished from two observations of different particles, if a particle cannot be located exactly? If a particle cannot be identified without uncertainty, how can one be sure what will happen to it in the future, or if the law of cause and effect is being obeyed?'[15] Naturally, the physical significance of this principle gave rise to a sense of insecurity among scientists, including Heisenberg himself.

For an account of the Tagore-Heisenberg talk one relies on the diary of D. M. Bose, the well-known Kolkata physicist. He informs that Sommerfeld[16] and Heisenberg visited India in 1928, 'both of whom stopped for a few days in Calcutta on their way to attend another International Conference in Japan. Heisenberg appeared one day without any previous introduction in the University College of Science. Some of us ... arranged a lunch at Firpo's [a famous restaurant in those days] for Heisenberg. Rabindranath was in Calcutta at that time. Heisenberg having expressed a desire to see him, it was arranged that we were to take him the same afternoon to Jorasanko (the poet's residence). On arrival, we found that Rathibabu [the poet's son] had arranged a fine tea for us. We left Heisenberg to have a talk with the poet. I do not remember what was the substance of his talk, but Heisenberg was very much impressed by the poet's illuminating personality which reminded him of a prophet of the old days.'

We get an idea of what transpired between the mature poet (he was sixty-seven at that time) and the young scientist (then only twenty-seven) from an interview given by Heisenberg to Fritjof Kapra. In his book *Uncommon Wisdom,* Kapra writes, 'In 1929 (actually 1928) Heisenberg spent some time in India as the guest of the celebrated Indian poet Rabindranath Tagore, with whom he had long conversations about science and Indian philosophy. This introduction to Indian thought brought Heisenberg great comfort, he told me. He began to see that the recognition of relativity, incommensurability, interconnectedness and impermanence as fundamental aspects of physical reality, which had been so difficult for himself and his fellow physicists, was the very basis of Indian spiritual traditions. "After these conversations with Tagore," he said, "some of the ideas that had seemed so crazy suddenly made much more sense. That was a great help for me".'[17]

We have seen above that already in 1914, Tagore was quoting the famous words from *Īsha Upanishad* (*Tadejati tannaijati taddūre tadvantike*) to assert that concepts like position, distance, nearness, movement, stillness, inside, outside etc. were not absolute. The philosophical difficulty faced by Heisenberg was that while his own immaculate mathematical calculations pointed to uncertainty and indeterminacy of fundamental physical concepts at the sub-atomic level, he could not reconcile himself to the physical absurdity that appeared to arise from this position. It is here that Tagore dispelled his uneasiness by showing that there indeed was a philosophical strand of thought in *Īsha Upanishad* that went well with Heisenberg's mathematical findings about physical reality.

It shows how Tagore read and interpreted the Upanishads in his own non-conformist manner. His familiarity with modern science reinforced that non-conformism. His interpretation and understanding of the Upanishads became increasingly individualistic and tinged with scepticism.

Creative Interpretation of the Upanishads

Tagore regarded the Upanishads not as revealed texts, but as having their base in the real temporal life of the people. In 1924, he wrote, '... the words contained in them had their full context in the life of the people of that period, who spoke them. Divested of that vital atmosphere, a large part of the language of these great texts offers to us merely its philological structure and not life's subtle gestures which express through suggestion all that is ineffable.' He was interested more in discovering those 'suggestions' than in theological reasoning: 'the Upanishads are based not upon theological reasoning, but on experience of spiritual life. And life is not dogmatic; in it opposing forces are reconciled – ideas of non-dualism and dualism, the finite and the Infinite, do not exclude each other.' As for the nature of the subtle 'suggestions' permeating the Upanishads, he clearly says that 'Suggestion has its unanalysable code which finds its depth of explanation in the living hearts of the people who use it. ... All poetry is full of such words, and therefore poems of one language can never be properly translated into other languages...'[18] He quotes from Keats' *Ode to the Nightingale* to drive home the point that mere philological correspondence with the English words will not make for a happy Bengali rendering. This analogy with poetry makes it clear that he is advocating a creative reading of the Upanishads. That is why he was able to express his own idiosyncratic, *non-theological* and sceptical understanding of reality on the one hand, and at the same time communicate with the new ideas of modern science. Heisenberg's experience is a case in point.

In a remarkable passage, Rudolph Otto, the well-known author of *Idea of the Holy*, comments on Tagore's spiritual yet non-theological perception of reality. Tagore 'wanted neither to expound any theological theory before us nor to lecture upon any condensed doctrine of Indian mode of belief, but to lay open his ... totally personal perception which by no means can be extricated from this person...' Narrating how Tagore explained to him the special significance of *Īsha Upanishad*, Otto noted 'how in reality an age-old religious perception here renews itself in a modern soul ... how an ancient heritage at the same time changes into a contemporary one ...'[19]

One would like to characterise this approach as 'cosmic scepticism', which would have been impossible without at least an aesthetic grounding in modern science.

Conclusion

Tagore is the direct and authentic negation of C. P. Snow's 'Two Cultures' hypothesis. Snow, a British novelist with a proper science background, had written in 1959 that his literary friends were arrogantly ignorant of even the rudimentary aspects of science. Asked what they knew about the second law of thermodynamics, his literary friends' 'response was cold: it was also negative. ... I now believe that if I had asked an even simpler question – such as, What do you mean by mass, or acceleration, ... not more than one in ten of the highly educated would have felt that I was speaking the same language'.[20] What did Snow find about the other side, the scientists? He noted that his scientist friends were curiously ill-read in literature: 'Most of them, when one tried to probe for what books they had read, would modestly confess, "Well, I've *tried* a bit of Dickens".'[21] In Britain, things may (or may not) have changed in the intervening half-century, but this more or less sums up the present situation in India.

Compare this mutual insensitivity with an Indian poet belonging to a non-European culture, brought up in a colonial environment away from the great happenings in twentieth century science, without any formal training in science, and yet writing such understandingly on modern physics and cosmology, and taking on people like Heisenberg and Einstein in their own terms! Science for Rabindranath was not a wall, but a launching pad, cosmic scepticism providing the escape velocity.

Notes

1. 'We meditate o the adorable glory of the radiant sun; may he inspire our intelligence.' Trans. S. Radhakrishnan, in *The Principal Upanishads* (New Delhi: Indus, 1994), p. 299.
2. Krishna Kripalani, *Tagore: A Life* (New Delhi: National Book Trust, India, 2001), pp. 19-20.
3. *Viśvaparicay* [An Account of the Universe, 1937], *Rabindra Rachanavali* (*RR*), Centenary Edn. Vol.14 (Kolkata: West Bengal Government, 1961), p. 822. Translation mine.
4. Abraham Pais, *Subtle is the Lord* (Oxford: Oxford University Press, 1997), p. 37.
5. Steven Weinberg, *Dreams of a Final Theory* (London: Vintage, 1993), p.194. Also, regarding Einstein's famously recorded belief in 'Spinoza's God', see p. 205: 'And it does not seem to me to be helpful to identify the laws of nature as Einstein did with some sort of remote and disinterested God. The more we refine our understanding of God to make the concept plausible, the more it seems pointless.'
6. 'What is the goal [i.e. substratum or basis or final principle] of the yonder world?' He replied, 'One should not lead beyond this world-support. We establish the *Sāman* on the world as support for the *Sāman* is praised as the support.' (1:8:7). Then Pravāhaṇa, son of Jīvala, said to him, 'Verily, indeed, your *Sāman*, O son of Śālāvat, has an end. If someone now were to say, "Your head will fall off," surely your head would fall off.' (1:8:8) Radhakrishnan comments: 'The enormity of the error is suggested by the statement that your head will fall off if one utters a curse like that.' See S. Radhakrishnan, *The Principal Upanishads* (New Delhi: Indus, 1994), p. 352. It is indeed remarkable that while a Brahmin school of thought emphasised 'on the world as support for the *Sāman*', King Pravāhaṇa, a *kßatriya*, should consider this empirical idea as an enormous and limiting error, so much so that 'your head will fall off if one utters a curse like that.' The Tagore-Einstein controversy, as it were, was being held here under a different set of terms of reference.
7. Rabindranath Tagore, *Mānuser Dharma* [Man's Religion, 1932], *RR*, Vol. 12, p. 575. Translation mine. Though of a similar title, the Bengali work is not the same as the English *The Religion of Man*.
8. *Viśvaparicay*, *RR*, Vol. 14, p.822.
9. Rabindranath Tagore, *The Religion of Man* (1931, New Delhi: Indus 1994), p. 9.
10. Ibid. p.14. One may note in passing the anticipation of the later 'electrical facts' like quarks in this passage.
11. *Mānusher Dharma*, *RR*, Vol. 12, p. 576. Translation mine.
12. Tagore's Ganot-connection was first brought to my notice by Professor Subir Kumar Sen of the Department

of Library and Information Science, Calcutta University.

13. *RR*, Vol.14, p. 348.
14. Talking at large of society, Arnold Toynbee expressed almost the same sentiments in 1976: '... the scientific spirit has, I believe, contributed to the present outbreak of lawlessness, especially in the field of sexual relations. The ethical merit of science is that it is dedicated to discovering and facing the truth. Science challenges all traditional beliefs, conventions, and habits. ... Children today are educated -- not merely formally but by the Zeitgeist -- to have a scientific zeal for the truth and a scientific contempt for shams. ... Present-day children are ready to believe that their parents do not practice what they preach about sexual relations or about anything else.' Arnold Toynbee and Daisaku Ikeda, *Choose Life: A Dialogue* (Delhi: Oxford University Press, 1987), p.19.
15. E. B. Uvarov and Alan Isaacs, *The Penguin Dictionary of Science*(London: Penguin Books, 1993) p. 464.
16. Sommerfeld also met Tagore at Santiniketan and had a talk with him on the upper terrace of Udayana. He has left a beautiful account of his impression of the poet.
17. Quoted in Dipankar Chattopadhyay, *Rabindranath O Vigyan*, Ananda, Kolkata, 2000, p. 252.
18. See S. Radhakrishnan, *The Principal Upanishads*, Appendix A, pp. 939-940.
19. Rudolf Otto, 'Preface to the book "Tagore's Confession",' *The Golden Book of Tagore* (1931), reprint(Calcutta: Rammohun Library & Free Reading Room, 1990), Addenda, p.17. English translation from the German by Saumendra Palit.
20. C. P. Snow, *The Two Cultures and a Second Look,* London: Cambridge University Press, 1959), 1974 edn., p.15.
21. C. P. Snow, *op. cit.*, p.12.

Ashish Lahiri is a noted scholar in History of Science. He is well known for his Bengali translations of J.D. Bernal's "Science in History" and Amartya Sen's "On Interpreting India's Past". His monograph, "Radhanath Sikdar : Beyond the Peak" and co-edition of Ananda-Puraskar (2001) winning Everyman's Dictioinary: English-Bengali are also significant.

The development of science centres in the Nordic countries

Asger Høeg

1. The birth of the first science centres.

The first "science centre" in the world, Urania, was inaugurated in 1888 in Berlin. This cultural institution consisted of a collection of high-precision instruments, an observatory, a scientific theatre and a hall of experiments for everybody.

Later, in 1906 opened Deutsches Museum in München (founding father Oscar von Miller); in December 1931, The Children's Gallery in Science Museum, London (founding father Sir Henry Lyons) and in 1938, the Palais de la Découverte in Paris on the success of the 2 million visitor exhibition "Arts and techniques in modern life" with the Nobel-price winner Jean Perrin as the founding father.

Inspired by these marvellous institutions, Frank Oppenheimer created the first modern science centre, Exploratorium in San Fransisco in 1969. The same year, Ontario Science Centre opened to the public in Toronto, Canada.

With Exploratorium and Ontario Science Centre (OSC) a new kind of institution was created. These two institutions had no collections, no research duties. They just wanted to exhibit science, not to explain their research but to explain science in general with the general public as the target group.

Both Exploratorium and Ontario Science Centre became very popular from the beginning. Exploratorium attracted more than a half million visitors and Ontario Science Centre attracted more than a million visitors a year.

A new kind of cultural institution had been born!

The science centres proved that there was a need (or desire) in the population to learn more about science. Attracting a high number of visitors, new science centres have been developed in many countries all over the world. First in North America and later in Europe, Asia, South America, Australia and Africa.

A rough guess tells us that today there are more than 500 science centres (in the sense of an institution that only have the diffusion of science as the raison d'etre and NO collections) in the world.

2. The first Nordic Science Centres

2.1 The Norwegian Science Centre, Teknoteket in Oslo

As early as in 1985, the first science centre in Scandinavia was established in the building of the Norwegian Technical Museum in Oslo. The centre was established by one man's dedicated work, Dag Kjelldahl. Teknoteket was a private institution directed by a board with representatives from Oslo University, local companies and the teachers association. It approximately welcomed 140.000 visitors per year. Teknoteket rented 1.000 m2 in the cellar of the Technical Museum. In 2000, Teknoteket tried to raise funds for a new building in downtown Oslo, but in vain. Therefore, Teknoteket became an integrated part of the public owned Norwegian Technical Museum. Later, Norwegian Technical Museum was adopted to receive operational funds from the Norwegian Science Center Committee (2004).

2.2 Teknikens Hus (House of Technology) in Luleå, Sweden

The House of Technology, in Luleå, Sweden was the next science centre to see the daylight. It was opened to the public on 27 May 1988. The initiative came from The Luleå High School that educates teachers. The driving force in setting up The House of Technology was AnnMarie Israelsson. The capital money for the project came from 130 different sources. The main sources were a private foundation and four major companies, mostly from the forest industry. Some of the collected funds were used as an endowment from which the interest could support the operation. Also, the community supported the operation considerable, but suggested at the same time that entrance should be free to all.

The centre receives approximately yearly 180.000 visitors and the exhibition area is 2.000 m2. From 1997 Teknikens Hus started to get operational support from The Swedish Governments grant programme.

2.3 The Finnish Science Centre, Heureka

Already in 1983, the first step was taken to establish the Finnish Science Centre, Heureka. By the initiative by Dr. Hannu Miettinen and Dr. Per-Edvin Persson, The

Science Centre Foundation was established on 21 December 1983 by the University of Helsinki, the University of Technology, the Federation of Finnish Learned Societies and the Confederation of Finnish Industries and Employers. The Foundation arranged a number of pilot exhibitions and on 28 April 1989, Heureka was inaugurated.

Heureka have grown to be one of the most appreciated science centers in the World. Especially, on the international scene, Heureka have played a pioneering role in conceiving The Nordic Science Centers Association (NSCF), one of the founding fathers of the European Network of Science Centers (ECSITE) and as the founding father of the Science Centre World Congresses.

2.3 Vitensenteret in Trondheim (The Trondheim Science Centre)

The second Norwegian science centre was established as a foundation in 1988 and the centre opened to the public in 1990. The capital money for the establishment came from the government, The county, the community, The Technical University of Norway, research foundations and private companies. Today, many of the founding institutions are still represented in the board.

The centre receives app. 90.000 visitors and the exhibition area is app. 1.500 m2. Vitensenteret in Trondheim also receives grant from The Norwegian Science Centre Committee.

2.4 Experimentarium, Copenhagen, Denm ark

Experimentarium's founding father was Esben Dragsted, the President of the Egmont Foundation. He visited Exploratorium in 1983 and came back to Denmark with the strong desire to open a similar institution in Denmark. The Egmont Foundation funded a feasibility study that was published in January 1986. Experimentarium's Deputy Executive Director up to 2010, Nils Hornstrup was one of the authors of the feasibility study. The conclusion of the study was that Denmark deserved a science centre. The study also concluded that it would be a good idea to start the project with a pilot exhibition. Experimentarium was founded on 6 November 1986 with funds from three foundations: Egmont, Augustinus and Thrige Foundations. The three foundations had each one representative in the Board. The three foundations asked Jannik Johansen from the Ministry of Education to serve as the President of the Board, a position Dr. Johansen is still holding today, 24 years later. Being the Board representative for the Augustinus Foundation, Peter Augustinus was a member of the Board from November 1986 and in 1998, he became the Vice President of the Board, a position that also he still holds.

The three foundations founded Experimentarium with 560.000 € to build the pilot exhibition. The work with the pilot exhibition started in the beginning of 1987. Nils Hornstrup was the project leader. Asger Høeg was appointed Executive Director on 1 April 1988 with the clear goal to secure the financing of a permanent science centre. The theme for the pilot exhibition was decided to be The Man's Body. The exhibition was named, "Man - Here is your body!" and opened to the public on 15 April 1988. In 90 opening days, the exhibition attracted 72.000 visitors in the area of 400 m2 in the old (hot!) carbarn in the centre of Copenhagen. The success was obvious. The Carlsberg Breweries decided to donate the 60 years old Bottling Hall North of 18.000 m2 in the Tuborg Area free to Experimentarium for period up to 20 years. The Minister of Education donated 1,4 M € to the permanent science center. And Egmont Foundation donated 3,5 M € to secure the operation after the opening.

On this basis, the fundraising campaign started in September 1988 and in January 1989, the needed extra 6 M € to the permanent science centre was secured. The money came mainly from foundations: Augustinus Foundation, Novo Nordisk Foundation, Lundbeck Foundation, Lego Foundation etc.

Her Majesty The Queen of Denmark inaugurated Experimentarium on 9 January 1991. The first year Experimentarium welcomed 530.000 visitors. But the following years, the visitor number fell to 300.000 per year. In 1994, Experimentarium introduced the temporary exhibition strategy with presenting one exhibition every year to stimulate more revisits. The first temporary exhibition was "Sport" from the Finnish Science Centre, Heureka that opened to the public in April 1989. In 1995 a new temporary exhibition area and The Great Stage was build. And in 2001, at the 10th Anniversary, the second temporary exhibition area was build.

Normally, Experimentarium introduces two new exhibitions every year. One in late January just before the winter holidays; one in early October just before the Autumn Holiday.

3. The support from the Governments to the Scandinavian Science Centres

3.1 The Danish case

It has been difficult to secure economic balance in the operation of Experimentarium. The endowment from Egmont Foundation was reduced in the first years after the opening year of 1991. In the years of 1992 – 1995, Experimentarium constantly asked the Government for operational support. The operational grant from Egmont Foundation was not totally spent, but everyone could see that Experimentarium could not operate without support from the Government.

In Denmark there has been a law supporting museums operations since 1958. And since 1977 there has been a law supporting the operations of zoos and aquariums. But there is still not today, a law that support science centres.

From 1985 to 1995, a large number of independent institutions with interactive pedagogical methods had been opened to the public in Denmark. These institutions had a great need of operational financial help. But these institutions were neither a museum nor a zoo. What to do?

In 1996, the Ministry of Education decided to set up a fund (1,1 M €) to support the operation of these so called "Institutions with interactive pedagogical methods" (among which Experimentarium was selected). Today, 13 very different institutions receive operational grants from this fund of 2 M € of which Experimentarium now receives 550.000 €. Among these institutions you will find a cultural centre in a cemetery (!), two Middle Age Visitor Centres, A Freshwater Centre and a Pre Historical Centre. As the reader can understand, this is not a fund for science centres. The common ground for these institutions is their communication methods.

As quoted, Experimentarium receives 550.000 € per year in operational grants but that is only 10% of the total operational expenditures of Experimentarium. This level of support is very low to a European standard.

3.2 The Swedish grant system to the science centres

In Sweden they look different on the idea of supporting the operation of the science centres. In Sweden from 1988 and forward, a great number of rather small science centres emerged (Tom Tits, Navet, Molekylverkstan, Innovatum and especially Universeum in Gothenburg). In 1997, the Swedish Government decided to set up a grant as support to the Swedish science centres. In 1997 the total grant was 2 M € which was given to 9 institutions. In 2010 the total grant is 3 M € to 14 centres. The supporting level per centre has not followed the inflation. The grant is given after criteria including the communication quality, the number of visitors and the size of the institution.

Many of the Swedish science centres are fighting hard to balance the operational income and expenditures. The level of support from the Government is not enough to define a stable operation of the Swedish science centres.

3.3 The Norwegian Science Centre Committee

In 2004, the author of this article was invited to be a member of the Norwegian Science Centre Committee (Vitensenterstyret, NSCC). From 2004 to 2007, it was lead by Yngve Astrup and from 2007 by Ragnhild Sohlberg. AnnMarie Israelsson was also invited as a member of the Committee. In 2004 there were only three science centres in Norway, Teknoteket (in the Norwegian Technical Museum), Vitensenteret in Trondheim and Vitengarden, Jærmuseet near Stavanger. The NSCC defined a very clear strategy. First of all, there should be a science centre in 6 Norwegian towns: Oslo, Bergen, Trondheim, Stavanger, Tromsø and Gjøvik. These 6 centres should fill a regional role as the disseminator of science to the schools in the region. The operational budget of a science centre should be at average 15 MNOK and 33% of that should be support from the NSCC. 33% should be regional and local support. And the rest should come from the visitors. With 6 centres, the Government intended to find 30 MNOK to the operational support.

With this strong statement, capital money became plenty in the mentioned cities. In 2004 , Norsk Hydro (Now Statoil) decided to donate 100 Million NOK in the occasion of the company's 100th Anniversary to a new science centre in Bergen. VilVite opened to the public in 2007 and receives more than 100.000 visitors per year. In Sandnes, near Stavanger, Jærmuseet raised 150 MNOK in capital money to open the Vitenfabrikken (The Knowledge factory) as a new institution in Jærmuseet. Innlandets Vitensenter in Gjøvik raised 60 MNOK and opened a smaller science centre to the public in 2007. In the little town Tromsø to the north in Norway, The Nornorsk Vitensenter has raised 90 MNOK to enlarge the Planetarium and establish a classic science centre which will open in 2011. Finally, the old science centre in Trondheim from 1988 will receive support from the Government to move to new buildings in connection with the Norwegian Technical University (an investment of the size of 200 MNOK).

In total, the Norwegian Science Center Committee have seen investments of the size 600 MNOK equal 75 M €.

Since 2004 two new science centres have been approved under the NSCC's programme: Grenland and Sarpsborg.

No other country in the World have experienced such a fast and successful development of science centres as Norway in the period from 2004 to 2011.

3.4 Conclusion concerning the support to the science centres in Denmark, Norway and Sweden

The movement of science centres came to Sweden in 1988 but the Government waited until 1997 to set up a grant programme. The programme's impact have been reduced since several new science centres opened to the public and started to receive grants. Since the total grant has not been adjusted, there is now less money per science centre than in 1997. The Swedish science centres fight for their lives because of the inadequate operational support from the Government.

In Denmark, the Government have paid very little attention to the importance of having science centres as useful institutions to stimulate the formal learning system. The Government have no strategy or programme for establishing more science centres in Denmark. In the south of Denmark, the factory Danfoss, have set up its own, private science park, Danfoss Universe. Being a private owned institution, Danfoss Universe do not ask for public support.

In Norway, the Government formulated a science centre strategy in 2004 and this strategy has generated 600 MNOK in investments in new science centres. In few years Norway will have 8 excellent science centres.

4. Experimentarium have grown into being a science communication centre

In the discussion how to disseminate science to the public, science centres are very interesting in one particular way: They only have one purpose, namely to communicate science to the public.

Science museums, natural history museums and technical museums have several purposes: To collect artefacts, to preserve them, to study them and to communicate the findings of the research and exhibiting the artefacts.

But science centres have only one purpose, to communicate science.

There is a contradiction in preserving and exhibiting artefacts. Perhaps this contradiction has been a limiting factor in the ability of museums to communicate science and technology?

Most science centres are self owned institutions such as foundations with the purpose to stimulate the public interest in science and technology.

Many of the science centres started with "Exploratorium-like" exhibitions with hands-on exhibits supplemented with demonstrations and science shows performed by "explainers". Having only one purpose – the dissemination of science – science centres became experts in "explaining science" both with exhibitions and with all other possible tools and methods. The science centres senior management was not only academic trained persons. The Directors could come from the corporate business or they could have a marketing or sales background.

When new demands and new opportunities appeared, the science centres quickly learned to respond and to use the new opportunitues in their exhibitions and programmes.

The Omnimax Films was a new media. Many science centres installed a Omnimax Theatre and attracted many visitors because of the appealing new technique. Later, the information technology provided endless possibilities of using new features to reach the audience. And with the entrance of the Internet on the scene, new opportunities emerged for the science centres.

In 2002, Experimentarium decided to become a multi media science centre. This means, that Experimentarium wanted to establish new departments where science and technology is communicated with all possible tools, media and methods that is at hand for those who want to communicate science and technology.

In 2003, a School Department was established. The department develop educational programmes. Xciters, Masterclass, MethodLab, Climate Minds, The Youth

Climate Summit are examples of school activities developed and operated by Experimentarium's new school department. Every year, the department announce a nation wide school competition.

Another department develop and conduct teachers training. The department also give lectures and courses to students and journalists. The MethodLab project has given lectures to 600 teachers in 2009.

A third department is producing educational material. Both as supplement to Experimentarium's numerous exhibitions and books, web based material and 3D experiments to the schools.

Experimentarium have also established a News Department where the "customers" are newspapers, Radio, TV and websites. The News Department balanced its operations after 18 months.

Also, a TV Department have been established. The department shall conduct Media Workshops at the Experimentarium and produce Youth Science Television.

Finally, Experimentarium is building up a Research Department that is making research in the science communication that is taking place in Experimentarium's departments.

If added that Experimentarium produce one or two exhibitions every year, is a partner in 4 EU projects of which Experimentarium is the coordinator of the large TWIST programme (2,3 M €) and that Experimentarium have a turnover of app. 2 M € every year by renting out and selling exhibits and exhibitions, one can understand that Experimentarium today is a middle sized communication company that has a large advantage of the immense synergy that is created when the numerous departments co-operate. This synergy is created both in terms of better science communication but also in terms of economic synergy.

Having grown to be a science communication centre, Experimentarium has been stronger and more capable of surviving. The income stream is coming from more diverse sources and the supporting network around Experimentarium has grown considerably.

Asger Høeg is the Executive Director, Experimentarium, Denmark since 1988. He is also the Associate Professor of Experience Economy in Copenhagen Business School. A past President of ECSITE (2004-2007), Asger Høeg was awarded the Knight of Dannebrog in 1986 and H.C. Ørsted Medal in Bronze in 2001.

Museums: The Future Forward

George Jacob

Dr. Saroj Ghose had posed an interesting question in the first Journal of *Propagation* about what the future would bring after Science Centres and Science Cities. *Future Forward* of museums and science centres is about possibilities of reshaping *lifestyles* that civil societies would imbibe and embed in times to come beyond the boundaries of science cities.

Museums are evolving and transforming themselves and the lives of their diverse audiences. They are seeking new definitions, new approaches, new meanings and new opportunities to enhance learning and bring about sustainable change. The spectrum of projects, industry intersect, living culture and mixed use studio concepts featured in this book offer a glimpse into the shape of things to come in the decades ahead, as museums continue to grow in myriad ways adapting to the changing needs of experiential learning and collective memory. What was traditionally within the domain of curatorial academe is increasingly being influenced by those considered "outside" the arteries of museology per se. Exhibits themselves are on the cusp of moving into the *fifth generation*- from the days of the early museums and science centers- from collections based presentations, story-based or themed to interactive hands-on and didactic, immersive scenic and multi-media infused learning environments to those exhibits that offer a visitor-driven presentation of projected outcomes and scenario-building experiences.

Scenario building experiences can be seen at many science and natural history museums on topics ranging from environmental policy, spread of infectious diseases, and mitigation of impending disasters- where visitors create and control scenarios and build-upon controlled and un-controlled evolution of vectors, transmitters and communication-building blocks to create a desired or un-desired impact on a given situation. The experiential analysis provides users of different age-groups to imbibe this layered process.

There is even a Museum of Tomorrow (MOT) in Taipei conceived by JUT Foundation, Chungtai Changhung Construction Company, and Ppaper, open 24 hours a day telling the visitors: "A better tomorrow awaits your visit" as it strives to connect creativity, culture, environment, innovation and aesthetics in different ways. MOT is designed to be nomadic and shift its location frequently. A different approach to learning spawned by the internet is inevitable both at individual and social levels that would impact museums as institutions of non-formal experiential learning, hubs of cultural gathering places and nodes of revival. *Chatrooms*, blogs, twitters and the *facebooks* of our times will soon see unpredictable transformational growth.

Fig. 1.

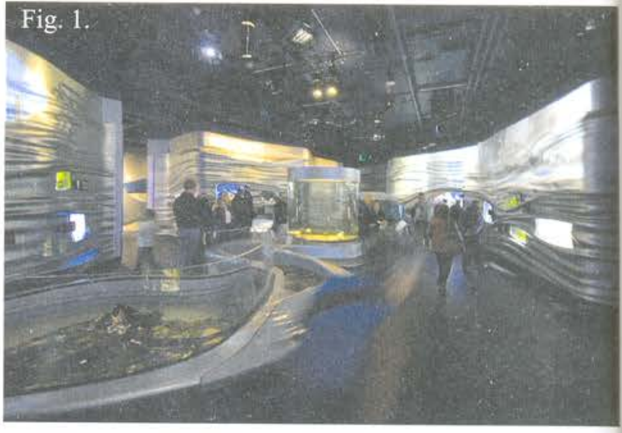

Fig. 2.

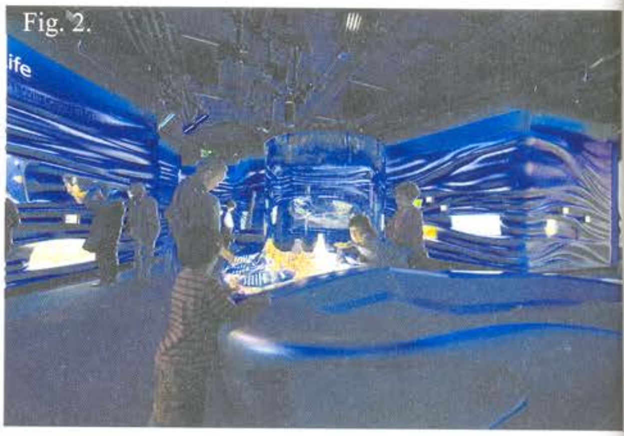

Fig. 1. & 2. : Gwanggyo Green Power Centre: A verdant urban interactive, organic, sustainable, eco-acropolis for 77,000 inhabitants designed by MVRDV Architects.

According to Tom Hennes, Principal of the New York based Thinc Design, the widespread public access to information and, even more importantly, the radical ease with which communities can surf through the Internet, open broad new opportunities for museums to be designed as flexible resources that can be accessed and utilized in many different ways by many different groups and individuals. This suggests a profound transition in the way museums interpret their collections and in the stories they tell, from a fixed narrative (the museum as preserver of culture or nature) to a dynamic system of narratives (the museum as a contact zone among communities, and a place of ongoing knowledge creation). It means that the design of museum must increasingly blend the core attributes of museums as *places* that hold authentic collections and the potential for exhibits to immerse their users in a particular experience, with the attributes of dynamic information systems to enable museums to generate evolving meanings and interpretation through a continuum of dialogue between their creators and their users.

Museum architecture is increasingly embracing a visual symbolism that is both timeless and futuristic in more ways than one. Globalization is beginning to affect cross-cultural dialog at levels and their impact on the future of museums is yet to be fully discerned. The catalytic coordination of professional resources and implementation dynamics is expanding possibilities of reach and outreach resulting in remarkable optimization of financial and intellectual resources.

Museum designers from different continents are cross-pollinating their creative rigors on to the creation of national museums obtuse to their own cultural backgrounds. Not only has the last decade seen an increased blurring of geo-political boundaries and national identities, it has experienced an unprecedented fluidity of resources that has re-shaped the manifestation of culture and heritage. From conventional leanings of curatorial practices to the frayed edges of neo-economic colonialism, museums face a plethora of challenges as they seek relevance while engaging diverse audiences.

Understanding the immediate needs of institutional planning, while addressing the larger human needs to learn from our shared and unshared histories, our many pasts, our present and our collective future, will increasingly shape the mission of museums in times to come. Resonance with the pulse of pluralistic societies in dynamic flux, will guide the process of exercising judgment, while advancing the continuum of museums as centers of education, equity and excellence.

Visual Vocabulary

Intercultural dialogue is changing the way architects and exhibit designers are approaching the visual manifestation of new museum projects creating a new level of broader subtlety in aesthetic appreciation. Examples abound in cross-cultural interface where one can observe a Japanese architects designing museums in Saudi Arabia or Irish architects transforming a museum project in Egypt or Dutch architects tackling urbanism with a cultural tilt in Korea. The architects and designers themselves are often displaced and nomadic in their spheres of education, training, travels, business locations, cultural sensitivity and interests. As their visual vocabulary expands, so does their palette of creative thought and innovative cross-fertilization. Their ability to rise above a traditional mindset and inspire generations, is often lauded by museum trustees and boards who are increasingly appreciative of fresh-thinking, sensitivity and its potential impact on regional development. Design for design's sake, can only carry the vision so far. Ultimately, the litmus test is in the resonance of the selected visual vocabulary with the institutional mandate of the museum based on the experiential content. The iconic buildings are 3D extensions of institutional brands seeking marketability and sustained credibility.

Globalization

While methodology of museum planning, process, procurement, production and project management are getting increasingly standardized, globalization is also triggering resource-pooling and out-sourcing of various services traditionally held to socio-geographic confines of a region. Design drawings, templates, construction materials, applications and expertise are streaming through a realm of fast pace transportation, internet and skype-laden design-build briefings and presentations. New software programs like Generative Components™, CATIA™ and many others are beginning to enable architects and engineers to generate free-form sustainable buildings, green materials and methods of integration. Programs and customized models offer options and alternate solutions reducing remodeling and redesign time significantly. The seamless integration of communication between museum clients, architects, designers, curators, museum educators, fund-raisers, board-members, trustees and potential donors, is already generating a transformational impact in the ways museums are being conceived, funded and built.

Even as the planning and design-build process transcends geo-political boundaries, crosses over time-zones and melts language barriers, globalization faces a bit of a conundrum associated with the sense of place. Traditional forms, motifs and indigenous techniques ensure cultural continuity and reinforce a sense of identity, while architectural experimentation promotes innovation, adaptability and osmosis associated with iterations of 'international style'. Architectural franchising is also on the rise where iconic national and cultural symbols are often dictated by the styles of lead architects and design principals. Walking into a museum in the United States could as well be linked with the experiential visit to a museum in, say, Germany- planned by the same master-planners, architects, designers and interpretive teams- all part of a subtle class of conforming to a standardized experimentation with space and methods of communication.

Synergistic Materials

Museum architecture and exhibit production of the new millennium is revisiting the conventional palette of construction material into a vocabulary that speaks to the exhibits in more ways than one. With material applications across conventional lines increasing exponentially like social networking groups through Venn-like intersects, bio-mimicry, bio-degradability and bio-energy are on the overdrive as never before. The building materials are beginning to promote values that answer their co-relationship with their environments. An intelligent adaptation of sustainable and smart materials is steadily making in-roads into a design dialog within the parenthesis of the emotive and the rational. Cross pollination of ideas from materials and technology firms to hi-tech research labs, automotive industry, defense and innovative applications developed by NASA (National Aeronautics and Space Administration) and other research institutions around the world, have yielded a plethora of possibilities for museum designers and architects with museum buildings open to increasing levels of experimentation in conjunction with an underlying sense of moral obligation to sustainable living.

Neo-Urbanism

Younger cities and those in the throes new development are seeing a more rapid revival than the established meccas of culture. The hunger and desire to experiment and make a statement is more pronounced in those domains than elsewhere, where a new breed of approaching and embedding museums is being spawned by the futurists. The Gwanggyo Power Centre designed by MVRDV Architects near Seoul, Korea is a futuristic 6.5 million sq.ft. neo-urban project that weaves in museums, leisure, education, office, retail, housing and other facilities into a continuum of dwelling, sustainable growth. The design is intended to mimic and offer a seamless link between constructed and natural environmental space. It was conceived in rings because the town has different needs for phasing, positioning, and size. Every structure has a terrace with plantations for outdoor life. The plantations are fed by a floor-to-floor circulation system that stores water for irrigation. The end result is a vertical park that reduces energy and water usage. Imagine a museum and science centre 'destination' embedded in this environment with exhibits that explain the mechanics of the functioning

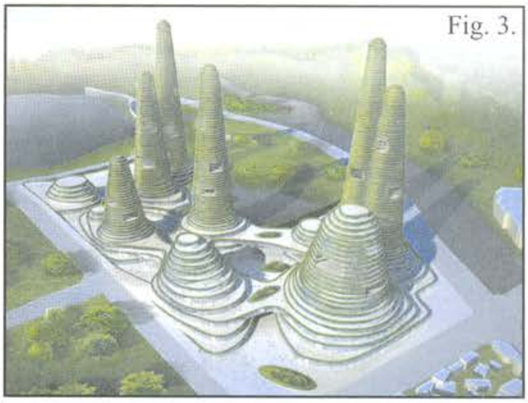
Fig. 3.

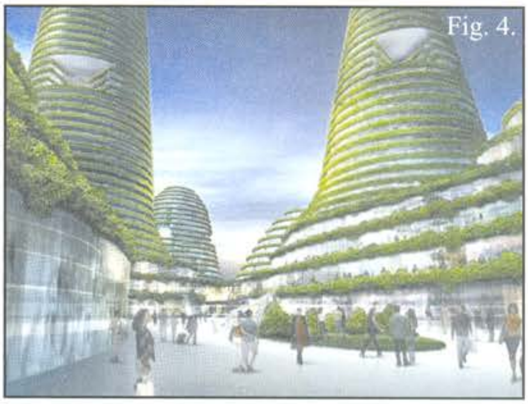
Fig. 4.

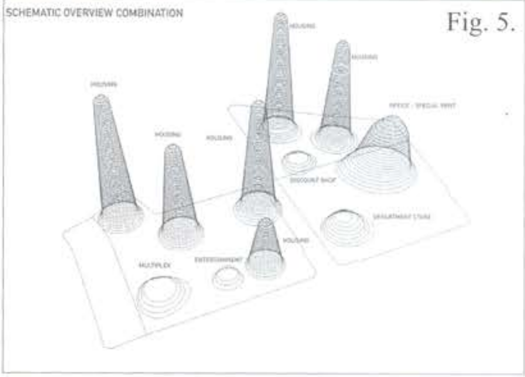
Fig. 5.

Fig. 6.

Fig. 3, 4, 5 & 6 : Water Planet Interactive Gallery: Blending dynamic immersion and reaching beyond the conventional at the California Academy of Sciences designed by Thinc Design.

of the gigantic complex, materials used and advantages to an inherent set of sustainable lifestyle choices.

Imagine, then, the breathtaking sense of possibility involved in the creation of an entirely new city whose primary purpose is to impact its residents in more than one ways. The challenge of Gale International's Songdo City in Korea is to create a city that inspires more than the footprint of the enabling technology and amenities that it provides for value-creation. Currently under construction, this incredible complex includes a 100 acre central park, schools, hospitals, hotels, retail, 30 million sq.ft. of residential space, an Ecotarium, Museum and 10 million sq.ft. of green space, among others, offering an unparalleled new level of excellence in living, learning and working, while remaining connected globally with the highest penetration of broadband technologies on earth creating a "ubiquitous city," or "U-City," in where major information systems (residential, medical, business, education, leisure) share data with computers are built into the houses, streets and office buildings that could yield unpredictable applications.

Extending the imagination a bit further is the Masdar City project- the most ambitious sustainable development initiative in the world today. When built, it will be the world's first zero carbon, zero waste city powered entirely by renewable energy sources taking living to a new level and will lead the world in understanding how all future cities should be built. This $20 billion project will be built in seven years located in Abu Dhabi linked to major destinations and businesses through a car-less, public transport system in conjunction with an innovative personal rapid transit system.

With architecture and new approach to commuting, communicating and sustaining growth on the rise, museums, science centers and exhibit environments and learning methodologies will undergo an unprecedented transformation at various levels. Flick, Twitter, Blogs and Wikipedia like phenomena are fuelling a web-based, highly interconnected complex social network of dynamic dialogue continuously seeking and creating new paradigms and definitions of learning. With Facebook crossing 100 million users in 2008 and You-Tube logging in 350 million user-hits a month, the rising tide of shared learning is forcing museums to seek a fresh perspective on outreach beyond their walls. As the strategy shifts from technology laden living environments to inspirational buildings and cities in which technology enables personal lifestyle choices and corporate innovation, its impact will be felt in the way museums of the future will be conceived, built, used and remembered. Science Centres are not mere containers that hold "content". Science permeates our lifestyle, our dwellings, our travel, our mobility, our connectivity and our thought process in continually evolving myriad ways adding a new meaning to "outreach". The triggers of learning and response follows a continuum with a museum or science centre-visit forming a part of this stream. Smart cities where this experience is extended and experimented with are the new learning environments for holistic exhibit experiences where the immersion is no longer simulated or contrived, but lived.

These transformative changes will invariably require an introspective adaptation of conventional training and currently offered Degree/Diploma/Certificate programs in Museum Studies. Forces shaping and influencing the present and future of museums and science centres are often external rather than from within the parenthesis of traditional museological rigours. This calls for bringing on-board an inter-disciplinary faculty of thinkers and project professionals into non-conventional virtual classrooms and live-labs of implementation that allow for exploration and enquiry in un-practiced ways.

With cooperation, collaboration, creativity and collective-sharing that forms the vanguard of the new age of digital consumption, seeds of inspiration will continue to be sown by museum professionals and those associated directly or indirectly with heritage, learning, and material culture. Every cyclical "seasonal" iteration will bring forth the blossoming of new ideas, harvesting a new appreciation for the world we live in.

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Science Communication : Mission accomplished?

Ingit Kr Mukhopadhyay

Abstract

In an old civilization like ours, with diversity found in immense proportions and not having a so called culture of science embedded in the Indian ethos, communication of Science and Technology to the people is a difficult mission but this activity is essential for our national development particularly at this juncture when our country's economy is in transition from its resource based structure to a more open knowledge based platform. With a substantial support from the Government and an inclination for promotion of Science communication activities observed in our Government policies, a sizable network of institutions and agencies for science communication has been established in India during the last few decades. But how far the mission of creation of a scientific temper among the masses has been achieved? Are we observing any attitudinal change among Indians towards Science and Scientific issues because of the Science Communication activities being conducted? If so, are we trying to measure the success or failure of our missions?

In India, regular assessment and evaluation of outcomes are not practiced as essential follow up actions for science communication activities. As a result, we do not know how effective our missions are. We must understand that the number of Science Centres set up in the country and the number of visitors entering into an exhibition or a Science Train are not sufficient indicators of the achievement or efficiency of our missions. Time has come for a closer look into the issue for appropriate action.

Prof M S Thacker, while examining the social background of great developments in Science and Technology in his Presidential address to the 45th Indian Science Congress, mentioned that "*The lesson in history and the requirements for scientific progress all point to the need for promoting the public understanding of Science, and it is to the creation of this understanding that we should dedicate ourselves*".

That was 1958 and India was putting utmost faith in Science and Technology for the reconstruction of a post-independence resurgent India. A large number of institutions for Scientific and Industrial research were already functioning at that time and soon, more such institutions were planned and established to anchor the development strategy of the Government of India firmly with the rock-solid support of Science & Technology. At this point of time, almost entirely under the auspices of the Government of India, a plan to set up organized science museums in the pattern of the similar organizations in Europe was taken up. The objectives of these institutions for public education were to impart Science & Technology education to the masses, particularly to the young students and to showcase the post independent achievement in Science and Technology in India. The growing popularity of the science museums in Pilani, Kolkata and Bangalore led the policy makers to form a task force to expand the science popularisation activities in the country. On the basis of the recommendations of the task force, a large number of new centres for communicating science was established throughout the country in the following decades.

The basic engine in the form of various forums, science museums, science centres, science clubs and science communication journals for '*promoting the public understanding of Science*' as mentioned in Prof Thacker's address was in full steam from the eighties. By this time, it was well understood that the most important medium for taking the messages of S&T to the masses need to be operating in a non-formal mode and that it would also be effective to supplement formal science education imparted through the formal system in schools, colleges and universities. The systematic approach for offering science education in the public domain gradually took shape and institutions and forums came up with a large number of activities and programmes to encourage the public to participate in non-formal learning of Science. In a contemporary parlance this mode of learning is being termed as 'free choice learning'. The result of this effort can now be seen as India having one of the largest networks for non-formal science communication in the world set up largely with the support of the central and state governments.

Having a sizable and functional network in the country for science communication for quite a long period now, one would expect to assess its objective achievements and impact on the society. However, in the Indian scenario, the achievements are being shown as the number of institutions created for the purpose or the total number of visitors to such portals for science communication. Rarely do we find any objective evaluation of the activities or programmes. To measure achievements, science communicators often record the growth of the infrastructure, its reach – how many towns or villages or kilometers have been covered, increase in visitor footfall or even growth in budget and revenue earning. All these indicators are valued attributes of the network strength but the visitor-centric achievement indicators are often ignored. In other words, science communication organizations tend to measure the success or failures of their missions by the growth of their own institutional values but rarely by the measure of the value added to the users of these institutions.

To elaborate on the above view, it is necessary to bring in the learning outcome factors associated with science communication activities which are designed and offered for engaging the targeted users. It is intended that the experience the user gets catalyses some *change* in him or her. This change may be in the attitude or behaviour or in the awareness, knowledge or skill of the user. There may be changes in multiple areas also. But if the programme design does not have any outcome goal fixed for it, the end result cannot be assessed or measured. All science communication efforts have an ultimate aim of social empowerment. For years since independence, we are strongly advocating for creation of a scientific temper among the masses by widespread scaling up of science literacy and awareness level on scientific and technological issues. However, this cannot be achieved through a single or a few activities. To spread science education and awareness in a country like ours, efforts from multiple agencies, governmental and non-governmental must work in tandem. In India, this joint endeavour is currently in place and growing but the results are not apparent or clearly comprehensible. The main reason for this is a profound lack of seriousness in evaluating the outcome indicators to understand the extent of achievement of our missions although on the other hand, there is no dearth of professional expertise in India for producing excellent exhibit hardware with which we intend to take the message of S&T to our people.

There are internationally accepted parameters to define the state of scientific temper in a community or educational outcomes in a non-formal setting. There are assessment procedures researched and followed in practice internationally for measuring such parameters and establishing correlation between intended outcomes with science centre visits or with participation in other science communication activities. In the US and in Europe, particularly in the UK, mission achievements of cultural institutions, science museums, botanical and zoological gardens are regularly done through scientific evaluation procedures. Australia is another country that puts serious effort behind such assessments. Notwithstanding the fact that learning outcomes are intangible to some extent, these countries rely on the continuous research that goes on to make the evaluation procedures more scientific and comprehensive so that more and more plausible correlations between museum visits or participation in science communication activities with the benefits derived out of them by the user communities can be established. In many countries, evaluation results of this kind determine the quantum of funding by the government or private sources. There are records that show further investments being denied for not being able to establish a favourable cost-benefit ratio in some science communication activities or even for not making evaluation results available to investors. In the recent past, some science centres in Europe, large and small, had to cut down on their activities and expansion plans because funding was denied for the want of evaluation data and in some cases, the same showing insignificant positive results. In India, however, such a situation has not yet arisen but a time will soon come when funding from the Government or other sources would depend on a clear showing of mission achievements, not just in terms of the number of users or in the number of science centres established or by the number of kilometers covered by a science train or a mobile science exhibition but by scientifically evaluated data on achievement of learning outcomes. The Indian network of science communication agencies would rather prepare for this unavoidable situation well in time and consolidate outcome assessment efforts without further delay. Fortunately, such moves have begun during the last few years, particularly in the National Council of Science Museums (NCSM) but a lot is yet to be done.

One of the deliverables expected out of science communication activities is a change in the attitude of the user to science and scientific issues that impact his or her life. Through various communication initiatives, the methods of science or important S&T issues are introduced to the users. Awareness and understanding leads to a change in attitude and this change is expected to generate a collective empowerment with which different sections of the society come forward to take part in the decision making process particularly in the scientific and technological issues that affect the community or the society in a broader frame. If a change in attitude takes place through an understanding of the methods of Science, one would perhaps start looking at events happening around him or her with a logical frame of mind. On a collective scale, this would generate a *scientific temper* in the community. The most conspicuous effect of such a change would be a reduction in the belief in superstitions and apathy to reform age-old social systems which are not based on scientific truth.

Non-formal science education initiatives are to supplement formal science education given in schools, colleges and universities. It is known that learning of science should involve demonstrations of principles and plenty of hands-on activities. The obvious limitations of our formal science education system in this area can be obviated by the participatory methods of learning offered in the non-formal system. Science communicators, particularly science centres, design many programmes for participation of students but whether these students are actually gaining better concepts of scientific principles or not are not assessed properly. This is where our effort, though sincere and painstaking, falters. In many countries, communicators regularly study the effect of science centre visits of students on the development of better concepts in them. It goes without saying that such studies are also important for museums, zoological gardens, aquaria, botanical gardens or other non-formal science communication organizations. There are established methods for such evaluation and with a little change to suit them in the Indian context; these techniques can be applied effectively.

Improvement of technical skill base in communities is another deliverable targeted by many science communicators. The outcome in this case is not very intangible but seldom have we found long term assessment of activities designed to measure the achievement of such missions. Some communicators try to show results by recording data on the number of community members to whom training modules have been offered or the number of villages or towns covered but these feeble evaluations do not usually highlight long term economic gains in the community as an outcome of the communication activities.

Science centres often act as catalysts between the experts and the users in the field. Birla industrial and Technological Museum (BITM) at Kolkata did a pioneering programme in the backward district of Purulia in West Bengal three decades ago in which appropriate agricultural implements were intended to be introduced for cultivation in the tribal areas of the district where traditional techniques and implements did not yield good crop. The land there is not fertile and inefficient agricultural practice led to abysmal poverty among the tribal population who did not possess any other skill to allay their hardship. Looking at the purpose, one must agree that it was a very important mission, whose success might lead to a significant change in the lives of the tribal communities. The programme involved agricultural experts under whose supervision appropriate implements were fabricated and field trials were rigorously done. BITM and the District Science Centre at Purulia functioned as the catalyst in this Lab to Land experiment all through b as adequate records were not kept and evaluation of t activity was not done on a scientific basis, t successes and failures of that important mission cou not be assessed or studied for future reference. Initial the results were encouraging and the tribal communi apparently took interest in the programme but stopped all together after sometime and no evaluat record is available to find the reasons for which t mission came to an end. Any scientific assessment the programme would have generated information immense value to science communicators. Anoth example of deficiency in programme design associated with the 'School Science Centre' project the National Council of Science Museums. The idea regenerating science communication activities at t school level had potential and a promise proliferating science popularization activities to t grassroots and to a very wide clientele. T programme, started two decades ago with great effor put behind it did not yield expected results and so became dormant. This programme, however, had evaluation component added as a follow up action b actual evaluation was feeble and not plausible to large extent as the data gathered from the schools d not match with the real functional status of the centr observed on physical inspection. Thus, a programm with good potential lost its direction because of t absence of a regular evaluation process.

Different persons come to participate in scien communication activities with different motivations a interests. Some have serious intentions of learning, sor visit museums and exhibitions to be aware of cutti edge science. Some others are chance visitors who do n have any motivation at all for the first visit. Scien communicators try to motivate respective audiences so to arouse and enhance their interest in various areas Science and Technology. This, unlike in most form settings, is a complex function as visitors to scien centres or other similar institutions have to cater to heterogeneous audience from varied socio-econom background, diverse age groups and of course dissimil degrees of initiation to Science. Effective programm therefore, need to have a judicious mix of educatio and entertainment components. The exhibits in permanent science gallery need interactivity and go display incorporated in the design for enjoya participation while the so called *edutainment* faciliti like Large Format Film shows or Laser shows need have supporting exhibits to validate the experience h by the visitor in these shows. Care must also be taken ensure that the visitors do not get negative or wro experiences *(scale models of howling dinosau exhibited in incorrect relative sizes).* On both coun assessment of the visitors' experience is importa

Otherwise, the main objectives for investing in exhibits or high-value facilities would be defeated. There is also the risk of science cities and science centres being classified as amusement parks in the public perspective. The permanent science communication facilities like science museums, science centres, zoo gardens and the like have an advantage that visitors can come there repeatedly as they wish to see new additions or to study the old exhibits more intensively as they encounter more of science in their science curriculum.

A count of such persons repeating visits roughly indicates the degree of importance science learners give to a particular science communication facility. For a temporary event like a Science Jatha, Science Fair, Children's Science Congress or a mobile exhibition like a Science Train where there remains no scope for the visitors to come back once the event is over at a particular venue, outcome assessment need to be on the spot. When the intended outcomes are not evaluated, the organizers have only the number of visitors or the number of venues as measures of the achievement of respective missions. There is no doubt that such science communication events are important for spreading Science awareness but these commendable endeavours certainly need careful evaluation of intended outcomes as an imperative follow up action on the spot.

Encouraging students to select a career in Science is another aim of many science communication activities. Some industrial sectors, like Oil & Gas, where trained manpower shortage persists most of the time, are now keen to launch long term science communication programmes right from the school level to encourage participating students to choose careers in specific industrial sectors. The success of such programmes can be ascertained only through a long term evaluation process through which career directions of the participants can be tracked. Information and data received through this process are extremely valuable to modify the strategy and delivery logistics of these very specific result oriented programmes.

So far, in this article, stress has been laid to highlight the importance of evaluation of science communication activities. Such activities are widespread in our country but very little effort goes into the assessment of the results of the missions as the aimed outcomes are considered to be intangible and in most cases, the evaluation techniques are beyond the capability and training of the communicators for putting them in practice. Professionals in this field are seldom hired by museums and similar institutions to conduct evaluation. In other words, the practice of assessment as a follow up action for science communication missions has not developed in India so far. Major thrust has been given to improve the infrastructure and the reach of the activities but hardly any investment has been directed for assessment of results derived by the society from out of the nationwide effort in this field.

A systematic approach is therefore needed to make up for this deficiency. To make a start, the following points may be kept in mind

1. Each science communication activity to have a reasonably defined goal. If such an effort is intended to effect a change in the user's level of comprehension of scientific principles or if it is attempted to change the attitude of the participants toward specific scientific or technological issues, the same must be considered in planning the mission.

2. The exhibits or programmes are to be designed in such a way that one or more measurable components are embedded in them so that the achievement of the goal can be assessed. This can be done by suitably incorporating these components in the hardware or software of the communication tools. *For example, a hands on exhibit explaining aerodynamic lift and drag can be followed by a game on choosing the right kind of wing section of an aircraft or the profile of a car. The selection in the second exhibit would indicate a measure* edge science, while some visitors look for entertaining *of the learning outcome of the preceding one for the visitor.* The key factor in the design of the second exhibit would be its ability to store the data of 'right' and 'wrong' selections. Often, such exhibits are built on digital platforms. There are other designs which can be followed to record the same data mechanically. The other alternative for gathering relevant information is by recording the visitor's response through direct evaluation techniques. There is a current debate on this issue in which some scholars express the view that insertion of measurable components in science communication activities may contradict the very approach of 'free choice learning' but for the time being, Indian communicators may bypass the debate and carry on with capacity building efforts in evaluation techniques.

3. Data gathered through evaluation must be reported to the exhibit or programme designers for modification of designs, if required. Data and resulting changes in design should be archived for future reference.

4. Visitor response is extremely important. They must be heard to achieve mission goals.

5. Interested groups in the audience are to be created across all sections of visitors. Programmes and exhibits must try to enhance the interest level of the visitor to scientific issues. For those who do not have any initial

motivation, new programmes are to be offered to attract them. To identify specific target groups who need special attention, front end evaluation is necessary. *The author, on a recent visit to the galleries of a national level science centre observed that a large group of students from a corporation run primary school walked through the gallery in single file without even looking at the exhibits. Probably the group was brought by the school to the science centre on an instruction from the authorities and the students apparently did not receive any memorable experience in their visit. In this case, the number of student visitors to the science centre increased but learning outcome was almost nil evidently.* For such student groups who visit the science centre almost daily, proper evaluation of their requirement must be done in consultation with their teachers and useful programmes are to be designed. The irony is, even though such visitor groups are regularly found in science museums, science centres or other non-formal science communication institutions, serious evaluation is seldom done to find out what is lacking in the offer and how more value can be added to it to engage the visitors more fruitfully.

6. Evaluation and impact assessment studies are to be continuous processes.

In India, a good infrastructure for science communication activities is in place. Support from the Government of India and state governments are also available to carry forward such activities. The intensity and spread of the efforts have grown substantially in the last decade. Institutions working in this field cannot ignore impact assessment studies any more as accountability and funding justification can be established only through scientific assessment of the impact made to the society by these institutions and agencies. Capability in this important follow up action can be built in stages.

Stage I

* Sensitise science communicators, exhibit designers and educators and most importantlythe heads of institutions and agencies in the field about the importance of conducting evaluation and long term impact assessment studies.

* Study the latest techniques being followed in other countries for evaluating learning outcomes. Plenty of published materials are available.

* Start small evaluation projects linked to the programme goals and analyse data.

* Gather data from all sources. Carefully check authenticity through corroboration.

* Heads of institutions may start allocating budget for activities on the basis of evaluated results.

* Train people in formative and summative evaluation techniques.

Stage II

* Identify important activities like permanent exhibitions in galleries, mobile science exhibitions including Science Trains, internet based communications etc. for systematic evaluation.

* Collaborate with organizations having experience in evaluation and impact assessment projects. There are several institutions abroad who are world leaders in this field. The Smithsonian Institution, Washington DC, University of Leicester and the Imperial College, London in the UK or the Australian National University in Canberra have ample experience in learning outcome evaluation. The NCSM network in our country which is already collaborating with the Smithsonian Institution for conducting its course on 'Science Communication' leading to MS degree may consider initiating a new collaboration entirely on this subject. The Education departments of a few major universities in India and other institutions like the Indian Statistical Institute or some evaluators in the private sector in India may also be contacted for collaborative projects. Moreover, there are several projects sponsored by the science centre networks, universities or the National Science Foundation of the US which can be tapped for data. NCSM, with its all India network and substantially large visitor base, may join hands with other science centre networks like ASTC or ECSITE to partially sponsor such studies by professionals and offer direct participation for the part of the project conducted in India. This will help in yielding good results not only in terms of data collected but also in building indigenous capability.

* Link budget demands with evaluation and long term assessment results. Programmes found more valuable and relevant to the society need more money to be spent on them while less successful ones need money for modifications and further trial.

* Carry out formative and summative evaluations extensively and regularly once the scientific methods are learnt and build up in-house expertise gradually.

Stage III

* Publish and exchange data.

* Encourage other science communication agencies to carry out evaluation studies even though their intended learning outcome focus may be different.

* Institute permanent fellowships to form dedicated groups of mission evaluators.

Notwithstanding the absence of a scientifically evaluated proof of the popularity or relevance of science communication activities in our country, it is encouraging to find that the demand for such activities has been high and growing. New science centres are being set up in different corners in the country and the states are always demanding more. The popularity of these institutions and the growing demand indicate that the activities conducted by these institutions are adding values to the communities. Our problem is that we are not very sure which of the activities are valuable and relevant and which need modification or discontinuation. Had we conducted adequate follow up assessment of the activities, the entire effort could be made more meaningful, efficient and cost effective.

It is heartening to note that of late, impact assessment studies and evaluation programmes have been initiated by some institutions in this field. This author has direct experience of being associated with one of them initiated by NCSM. The studies to assess the personal and societal impacts of the activities conducted by one of the major science museums under NCSM were conducted following methods similar to those followed by others earlier in the international field. The adoption was somewhat feeble having some deficiency in formulating the study questionnaires for school students and teachers but the analysis of the collected data yielded valuable and encouraging information about the impact of the activities of the particular science museum. It was the first long term impact study conducted by NCSM and by nature was very different from the routine visitor studies conducted in various science centres and other non-formal science communication agencies. Such pioneering efforts need to be taken further to position the Indian science communication efforts at the forefront in the international scenario on our own strength.

Professor Thacker in his Science Congress speech said '*If history has a lesson, it is this : everything that sustains and progresses comes as an upsurge from within, not as a result of something imported or invited, from without. Nothing sustains unless it is of the people and by the people.*'

Our own science communicators, dedicated and dynamic, will certainly take this challenge.

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World War II and its Impact on the Studies of Magnetic Resonance: 1939-1973

Jayanta Sthanapati *and* ***Kunal Chattopadhyay***

Introduction

Though the Scientific Revolution and the Industrial Revolution had taken place much earlier, it was from the twentieth century that science had had a massive and novel impact on the conduct of warfare. World War I had shown the development of poison gas and Germany's production of synthetic oil, both the products of the technological revolution based on the chemical industry. In the inter-war period the importance of scientific research for technological innovation steadily increased, thereby laying the basis for further military-scientific research and invention.

The World War II was fought from 1939 to 1945 between two rival military alliances, called the Allies and the Axis, involving most of the powerful nations of the world. The prominent members of the Allies were the United Kingdom, the erstwhile Union of Soviet Socialist Republics, and the United States of America. Three principal partners of the Axis alliance were Germany, Japan, and Italy. The war began in Europe in 1939 with the invasion of Poland by Nazi Germany, and ended in 1945 with the victory of the Allies over Germany and Japan. After the outbreak of World War II, Nobel Prizes in Physics were not awarded in 1940, 1941 and 1942. However, Nobel Prizes in Physics awarded in 1943 and 1944 paved the way for phenomenal advancement of the field of magnetic resonance between 1946 and 1973. It is worth mentioning that four radical innovations during World War II were directly stimulated by scientific research for military purposes: radar, sonar, the proximity fuse, and the atom bomb. The decisive role of radar in the Battle of Britain is widely known. But it was also crucial for the Germans in the Eastern Front, for the Red Army failed to destroy the Luftwaffe on the ground before the Wehrmacht's assault on the Kursk salient on 5 July 1942[1]. Once all this research was carried out, however, it could not be confined to the military sphere. Neither the scientists who carried out the researches, nor capitalism with its constant search for markets, could rest content with one off applications restricted to the military field. For us, the main issue is how war stimulated scientific research and turned the curiosity of scientists into one specific direction.

The emphasis of the present article is on the research activities of the American, British and Russian scientists during the World War II in the field of electrical communication who, based on such knowledge and experience, made various discoveries in magnetic resonance, maser and laser in the years immediately following World War II and also during the cold war period. Historically it re-established the belief that military conflict often led to decisive technological advances, which in turn could accelerate development in many areas of science and technology beneficial to mankind.

The Nobel Prize in Physiology or Medicine for 2003 was awarded for discoveries concerning magnetic resonance imaging (MRI), a breakthrough in medical and diagnostic research. MRI is a non-invasive, non-x-ray and non-computer tomography diagnostic technique that uses nuclear magnetic resonance to form cross-sectional images of the human internal organs. Magnetic resonance drew attention of the scientific community immediately after its discovery in 1938. Various forms of magnetic resonance experiments, discovered between 1938 and 1956 included molecular beam magnetic resonance (MBMR), electron paramagnetic resonance (EPR), nuclear magnetic resonance (NMR), ferromagnetic resonance (FMR), and electron nuclear double resonance (ENDOR). Between 1952 and 1960, microwave amplification by stimulated emission of radiation (MASER), an offshoot of magnetic resonance, was developed. Maser was the forerunner of light amplification by stimulated emission of radiation (LASER). The importance of magnetic resonance and its associate branches of science can be judged from the fact that ten Nobel Prizes were awarded to fourteen scientists between 1943 and 2003.

Magnetic field effects on atoms

In 1896, Dutch physicist Pieter Zeeman (1865-1943) discovered that emission spectral line of an atom splits into several components when the atom is subjected to a static magnetic field[2]. The splitting (as explained later) occurs basically due to interaction of the magnetic moment of the atom with the external magnetic field. Elaborate explanation of this effect was given jointly by Zeeman and another Dutch physicist Hendrik Antoon Lorentz (1853 - 1928). The Nobel Prize in Physics 1902 was awarded to Zeeman and Lorentz for their researches into the influence of magnetism upon radiation phenomena.

In 1921, German physicists Otto Stern (1888-1969) and Walther Gerlach (1889-1979) conducted a fundamental experiment on the structure of matter at Frankfurt University[3]. By shooting a beam of silver atoms through an inhomogeneous magnetic field onto a glass plate, they discovered that the beam splits into two distinct beams instead of broadening into a continuous band.

By the early 1930s, physicists knew that matter is composed of atoms, consisting of positively charged protons and neutral neutrons in the nucleus, around which negatively charged electrons revolve. Electron was discovered by J. J. Thomson in 1897. Ernest Rutherford discovered proton in 1918, and James Chadwick proved the existence of neutron in the nucleus in 1932. It was also known that both protons and electrons have intrinsic spin about an axis. The strength of the magnetic field produced due to motion or spin of electric charges in an atom is called *magnetic moment* or magnetic dipole moment. The *electron magnetic moments* associated with atoms have three origins – electron orbital motion, the spin of electron, and the change in orbital motion caused by an external magnetic field. The *nuclear magnetic moment* is the magnetic moment of an atomic nucleus and arises primarily due to spin of the protons.

The Stern-Gerlach experiment thus showed the quantisation of electron spin into two orientations. This was a major contribution to the development of quantum theory of the atom. With the help of this experiment they could also determine the magnetic moment of the silver atom. In 1933 while working at University of Hamburg, Otto Stern measured the magnetic moment of the proton by using a molecular beam method. Stern was awarded the 1943 Nobel Prize in Physics for his contribution to the development of the molecular beam method for studying the characteristics of molecules and for his discovery of the magnetic moment of the proton.

Discovery of molecular beam magnetic resonance

Isidor Isaac Rabi (1898-1988), a physicist of Columbia University, New York, visited Stern's Laboratory at Frankfurt, Germany, in 1927. Beginning early 1930 he made several improvements to Stern's experimental set up with a view to measuring nuclear magnetic moment. In 1937 he succeeded in developing a resonance method to measure nuclear magnetic moment of atoms[4]. An atom has certain fixed energy levels and transition between these levels can take place by means of emission or absorption of electromagnetic radiation. Transition between closely spaced levels can be induced by means of radio-frequency radiation, and this forms the basis for the resonance method, introduced by Rabi. In his method a beam of atoms is passed through an oscillating field, and if the frequency of that field is right, transition between atomic levels can take place. Rabi was awarded the Nobel Prize for Physics in 1944 for developing a "resonance method for recording the magnetic properties of atomic nuclei". Polykarp Kusch (1911-1993), an associate of Rabi in molecular beam magnetic resonance (MBMR) work, did the first measurement of magnetic moment of electron in 1947 and was awarded one half of the 1955 Nobel Prize in Physics.

Development of microwave radar during World War II

Much before the advent of World War II, radio systems for detection and location of distant targets (later called radar) were developed independently in Italy (1933), Japan (1933), France (1934), Germany (1934), UK (1934), USSR (1934), USA (1934) and the Netherlands (1936). The radar was considered as a means of early warning of air-attack. These radars operated mostly in VHF range, i.e., from 30 MHz to 300 MHz frequency band. Attempts were, however, on to increase the operating frequency or, in other words to use shorter wavelengths, in order to get greater accuracy and better resolution. It was realised by the British radar technologists that ideal wavelength of radar should be 10 cm[5].

Prior to World War II, Prof. Mark Oliphant of Birmingham University, UK, had seen a klystron developed by Stanford University, USA, but its output power was insufficient to be used as a transmitter for microwave radar. In December 1939 he asked two young physicists, John Randall and Henry A.H. Boot of Birmingham University, to develop a microwave generator of higher power output. Within two months they produced a new kind of cavity magnetron, an improvement of the cavity magnetron developed in 1935 by Hans Erich Hollmann in Berlin, and fitted that to an experimental microwave radar in May 1940[6].

A seven-member team of British Technical and Scientific Mission, led by Henry Tizard, who was the Chairman of British Aeronautical Research Committee visited USA in September 1940, to exchange wartime secrets with the Americans, in fields such as radar, nuclear research and jet engines. The British delegation also disclosed all technical details of the cavity magnetron to their American counterpart, which made development of efficient centimeter radar or microwave radar possible.

The Radiation Laboratory was set up at Massachusetts Institute of Technology in Cambridge, USA in October 1940 to develop microwave radar systems. A large number of American physicists working on basic physics research in various Universities were appointed during the war years at the Radiation

Laboratory to conduct research on the development of radar systems. Similarly, many British physicists had to stop their basic research and carry on radar research under the British Admiralty. Immediately after the end of World War II both British and American physicists went back to their respective physics departments and subsequently did significant work in the field of magnetic resonance[7].

The phenomenon of magnetic resonance

The phenomenon of magnetic resonance is exhibited by the spin systems of many atoms and molecules whereby the spin systems absorb energy at specific (resonance) frequencies when subjected to a constant magnetic field and an alternating electromagnetic field. Resonance takes place only when the frequency of electromagnetic field comes in unison with the precessional frequency of the spin system. Magnetic resonance provides an experimental method for determining γ- the ratio of the magnetic dipole moment to the angular momentum of a particle directly from measurement of a frequency and a magnetic field. And once it is known, such measurements give important information about the 'environment' of the spin[8].

Discovery of electron paramagnetic resonance

Electron paramagnetic resonance (EPR) or electron spin resonance (ESR) is a technique of detecting magnetic resonance arising from magnetic moment of unpaired electrons in a paramagnetic substance or in a paramagnetic centre in a diamagnetic substance.

Eugeny E. Zavoisky (1907-1976), an Assistant Professor of Physics at the Kazan State University, USSR discovered electron paramagnetic resonance (EPR) in 1944. In his experiments he used manganese sulphate, copper sulphate and anhydrous chromium chloride. His discovery of EPR was, however, not accepted immediately. He was asked by the Academy to repeat the experiments at the Kapitza Institute of Physical Problems in Moscow. Zavoisky assembled the EPR spectrometer and demonstrated the EPR in hydrous copper chloride. He got his doctoral degree in 1945. Zavoisky's first paper announcing discovery of EPR appeared in Russian in 1945[9]. Due to the international political situation at that time, Zavoisky's outstanding work remained unnoticed in the West. In 1940 Zavoisky started a project to observe proton magnetic resonance. Although he detected such resonance in May 1941, he could not observe it in later attempts, presumably due to failure to obtain homogeneous magnetic field[10]. Between June 1941 and August 1943, he had to discontinue his research work due to war. At the end of 1943, he started work in search of paramagnetic resonance. Although Zavoisky was not benefitted from wartime technical exposure, he had sound knowledge in electrical communication techniques in the radiofrequency range. As a result he could develop the EPR spectrometer for his experimentation[11].

Discovery of ferromagnetic resonance

Ferromagnetic resonance (FMR) is a spectroscopic technique broadly similar to EPR and probes the magnetisation of a ferromagnetic sample resulting from magnetic moments of dipolar-coupled but unpaired electrons.

James H.E. Griffiths (1908–1981) led a team at Clarendon Laboratory during the first half of the war in the development of progressively shorter wavelength klystrons – 10-cm (S-band), 3-cm (X-band), 1.25-cm (K-band), and finally 8-mm (Q-band). During the second half of the war he was Secretary of the Communications Valve Development Committee in London. After the war Griffiths returned to Clarendon Laboratory. He decided to study the permeability of ferromagnetic metals like iron, cobalt and nickel. He used surplus military apparatus for his experimental studies in the microwave region[12]. He discovered ferromagnetic resonance[13] and published his work in Nature in 1945[14].

Discovery of nuclear magnetic resonance

In the winter of 1945, Edward Mills Purcell, Robert V. Pound, and Henry C. Torrey discovered nuclear magnetic resonance (NMR) in condensed matter by nuclear resonance absorption experiments at Harvard University, USA[15]. About five weeks after their discovery, Felix Bloch, William W. Hansen and Martin E. Packard independently discovered NMR by nuclear induction experiments at Stanford University in the West Coast of USA[16]. E. M Purcell (1912-1997) shared the 1952 Nobel Prize in Physics with Felix Bloch (1905-1983) for their independent discovery of NMR, now widely used to study molecular structures and to measure magnetic fields. Both the groups observed that when certain nuclei, having effective nuclear spin, were placed in a magnetic field and a radiofrequency radiation applied, they absorbed energy from the radiofrequency radiation and re-emitted this energy when they returned to their original state.

Dutch physicist Cornelis Jacobous Gorter (1907-1980) made two unsuccessful attempts to observe nuclear magnetic resonance in condensed matter – one just before the success of Rabi's group in Columbia[17] and the other much before the discovery of NMR by Purcell and Bloch[18].

Purcell graduated from Purdue University in electrical engineering 1933 and thereafter spent one year at Technische Hochschule, Karlsruhe in Germany. He joined Harvard University in 1934 for doctoral work, received PhD in 1938, and served as an instructor in physics till 1940. During World War II, he headed a group at the Radiation Laboratory at MIT which developed advanced microwave radar.

Robert Vivian Pound (1919-2010) began his professional scientific work during World War II as a member of the Radiation Laboratory at MIT. One of his first contributions there was the technique of "broad banding". He became responsible for the design of microwave mixers, and developed several devices based on the Magic-Tee, including mixers and frequency discriminators that made possible the stabilisation of the frequencies of microwave oscillators. In 1945 he arrived at Harvard as a Junior Fellow. In a communication Pound revealed, "Ours was the first to succeed in detecting NMR in condensed matter, as distinct from beams, and it was at least five weeks earlier than that of F. Bloch, W.W. Hansen, and M. Packard. The dates on our 'letters', in successive issues of the Physical Review were December 24, 1945 and January 29, 1946. Our experiment was conceived and carried out in the three months between September and December 15, 1945 as a spare-time activity whilst we were full-time employees at the Radiation Laboratory at MIT. We were all mainly engaged in writing the books that preserved our wartime advances in technology. I was responsible for Volume 16, Microwave Mixers, H.C. Torrey was responsible, with C.A. Whitmer, for Volume 15, Crystal Rectifiers, and E.M. Purcell was responsible, with C.G. Montgomery and R.H. Dicke, for Volume 8, Principles of Microwave Circuits, among others. Bloch and Hansen left their wartime involvements in the spring of 1945 and took up full-time academic teaching and research at Stanford, where they started work on the 'nuclear induction' experiment in that spring"[19].

Felix Bloch (1905-1983) was a Swiss physicist who worked mainly in the US. He was educated at the Federal Institute of Technology, Zurich, Switzerland and did doctoral research under Werner Heisenberg at University of Leipzig, Germany. As a refugee from Nazis he arrived at Stanford University in 1934. He became a naturalised American citizen in 1939. In collaboration with Luis Alvarez he made the first experimental measurement of magnetic moment of the neutron. During World War II, his fundamental physics research works were halted. During 1942-1944 he worked for the Manhattan Project, whose goal was to produce an atomic bomb. He thereafter joined the Radio Research Laboratory at Harvard University and was an associate group leader in counter-radar research. The knowledge of radio technique acquired at Harvard helped him immensely to set up the nuclear magnetic induction experiment at Stanford, immediately after the war[20]. William Webster Hansen (1909-1949) was a professor of physics at Stanford. He started work on the problem of detecting approaching aircraft in 1937. The same year, in collaboration with Russell H. Varian and Sigurd F. Varian he developed the klystron tube, a microwave generator, essential to radar technology. During World War II, he made significant contribution towards development of cavity resonators, radar devices and aircraft landing systems. In 1945 he became Head of Stanford's Microwave laboratory[21]. Martin Packard came to Stanford University's physics department as a PhD student to work with Bloch and Hansen on the yet untested but well conceived idea of nuclear induction. He had previous experience of working on passive microwave devices[22].

Other early EPR experiments

British physicist Brebis Bleaney (1915-2006) was a key figure for outstanding progress of post-World War II physics research at Oxford University. During 1937 – 1939, he conducted research in low temperature physics.With the outbreak of war Bleaney's work was interrupted. He was employed by the Oxford University for the Admiralty, primarily to develop microwave radar technology. His work resulted in the development of tunable reflex klystrons at 3-cm (X-band) and 1.25 cm (K-band). In 1943, J. R. Zacharias, from MIT Radiation Labs of USA, who was a coworker of I.I.Rabi in discovering molecular beam magnetic resonance (MBMR), visited the Oxford Group. He realised that the K-band reflex klystron developed by the British group was more reliable and easier to manufacture than the one developed in USA by the Bell Laboratories. As a follow up action, Bleaney was invited to visit MIT Radiation Lab with the klystron. There he could convince Raytheon of Waltham, MA to manufacture them on a large scale[23].

After the war Bleaney became a lecturer in physics at Oxford in 1945. About the same time the observation of nuclear magnetic resonance (NMR) in solids in the United States suggested that the analogous electron paramagnetic resonance (EPR) could be observed in solids using microwave, and a major step was taken by Bleaney at Clarendon Laboratory. In his words, "James Griffths had discovered ferromagnetic resonance in 1945. This and news from USA about NMR made it obvious to me that EPR was an important technique. I started my pupil/graduate student D.M.S. Bagguley on it in October 1946; this was before we heard of Zavoisky – Russian Journals were not arriving nor were they translated. ....Because I was still busy with ammonia, DMSB worked with Griffiths and discovered the EPR spectrum of copper sulphate[24]. My first publication on EPR was 'Paramagnetic Resonance at Low Temperature in Chrome Alum'. For all this work (EPR) we used klystrons and microwave components from our wartime work, very simple cryostats (for liquid oxygen and hydrogen) made in the laboratory workshops, and rather cheap magnets. Little outside funding was needed – a modest annual grant from British Admiralty (our war-time employers) was continued for a number of post-war years"[25].

Within a few years Bleaney and his group conducted extensive electron paramagnetic resonance studies of a wide range of compounds of the transition groups (3d, 4d and 5d), together with the lanthanide (4f) and actinide (5f) groups. These were explained by M.H.L. Pryce and his associates, A. Abragam, K.W.H. Stevens, R.J. Elliott and others. Pryce worked under the Admiralty in the Signal Establishment during the first part of World War II. Both Abragam and Stevens also served in World War II. Elliott, however, graduated in mathematics in 1949 and published his first work on paramagnetic resonance survey in 1951 jointly with his doctoral guide Stevens[26,27].

In USA, American physicist David Halliday (1916–2010), who was internationally acclaimed since 1960 as a physics textbook writer, discovered electron spin resonance immediately after the end of World War II. He wrote in 1988, "I was born in Manchester, England but moved with my parents to Pittsburgh, Pennsylvania (USA) at age six. I spent most of my life in that city, receiving my BS, MS and PhD degrees from the University of Pittsburgh, the later degree in 1941. I spent the war years at the MIT Radiation Laboratory, on microwave radar problems, an experience that formed an ideal preparation for my later work in electron spin resonance. In 1946, I returned to the University of Pittsburgh as Assistant Professor of Physics and remained there, becoming successively Associate Professor and Professor of Physics. I can tell you that the idea of electron spin resonance occurred to me independently, in consequence of a colloquium talk that I gave, at the University of Pittsburgh, on Purcell's nuclear resonance work. I immediately wrote to my friend Robert Cummerow, who had just missed finishing his PhD programme before the war, and invited him to Pittsburgh to work on this subject as his thesis. This he did, completing his thesis work in 1946-47. I also wrote to the office of Naval Research and obtained a research grant for the work"[28]. Halliday and Cummerow observed electron spin resonance in two salts in 1946[29]. The hardware of Halliday's experiment were of military radar origin, viz., a Navy 3-cm test set (type AN/APW – 3A) along with a klystron oscillator 723 A/B from Bell Labs[30]. Halliday, at the time of their discovery of electron spin resonance in 1946, was unaware of similar work of E.K. Zavoisky at Kazan University done in 1945, as neither Russian journals were available in USA, nor were they translated into English then. In Halliday's words "only when our first results were well in hand did I hear about the work of Zavoisky. Let me make it perfectly clear that the priority of discovery is his, based on his undisputed earlier publication"[28].

Other early NMR experiments

Bernard V. Rollin (1911 - 1969) was a British pioneer who conducted first nuclear magnetic resonance experiment in England, at Clarendon Laboratory of Oxford University. In 1940, Rollin invented the reflex klystron at a wavelength of 10 cm. During the war years Rollin worked on development of cavity magnetron used in Radar. Rollin built the first NMR spectrometer and published his paper titled 'Nuclear Magnetic Resonance and Spin Lattice Equilibrium' in November 1946[31]. British physicist Edward Raymond Andrew (1921-2001) also made extraordinary impact on the field of nuclear magnetic resonance. During the war years, 1942-45, as a Scientific Officer at the Royal Radar Establishment in Malvern, England, he was involved in studying the effect of X-band radar. During 1948-49, as Commonwealth Fund Fellow he worked under Edward M. Purcell at Harvard University, USA[32].

Discovery of oscillatory field method of MBMR

In 1949, American physicist Norman Foster Ramsey (b. 1915) modified the MBMR method of Rabi[4] by introducing two separated oscillatory fields, which increased the accuracy of the older method[33]. His method found application in the hydrogen maser and in atomic clocks. Ramsey was awarded the 1989 Noble Prize in Physics for his invention.

Ramsey was the first graduate student of I.I. Rabi at Columbia. World War II interrupted molecular beam research at Columbia University from 1940 to 1945. He was later involved in establishment of Columbia Radiation Laboratory, which produced 1-cm wavelength radar. Ramsey initially headed a group at MIT Radiation laboratory for development of radar at

3-cm wavelength and thereafter, worked at Washington as a radar consultant to Secretary of War. In 1943 he went to Los Alamos, New Mexico, to work on the Manhattan Project. At the end of the war he returned to Columbia to join Rabi's group to conduct research in MBMR[34].

Discovery of electron-nuclear double resonance

Electron-nuclear double resonance (ENDOR) is a magnetic resonance spectroscopic technique to determine hyperfine interactions between electron and nuclear spins and thus provides detailed molecular and electronic structure of paramagnetic species. George Feher introduced this technique in 1956 when he observed nuclear magnetic resonance via electron spin resonance line[35], at Bell Laboratories.

Invention of MASER and LASER

Albert Einstein (1879-1955) in 1917 introduced the concept and theory of stimulated emission of radiation[36]. He identified three fundamental types of interactions between matter and light, namely, absorption, spontaneous emission, and stimulated emission. A new concept of amplification and generation of electromagnetic radiation, using stimulated emission of radiation by atomic systems was introduced in 1954 at the Columbia University in New York, USA and at Lebedev Physical Institute in Moscow, USSR. The work of American physicist Charles Hard Townes (b. 1915) and that of Russians Aalekshandr Mikhalovich Prokhorov (1916-2002), and Nikolay Gennadiyevich Basov (1922-2001) led to the invention of the MASER (Microwave Amplification by Stimulated Emission of Rradiation) and the LASER (Light Amplification by Stimulated Emission of Radiation).

Townes received PhD degree in 1939 from California Institute of Technology. He served in Bell Telephone Laboratories from 1939 to 1947. During the war years he was involved in designing radar bombing system. After joining Columbia University as a faculty in 1948, he applied his knowledge of microwave radar techniques to atoms and molecules as a potential new basis for controlling electromagnetic waves. In 1951 Townes conceived the idea of using ammonia molecules to amplify microwave radiation. In collaboration with his two students, G.P. Gordon and H. J. Zeiger, he obtained the first amplification and generation of electromagnetic waves by stimulated emission and coined the term MASER for this device[37].

A.M. Prokhorov had graduated from Leningrad State University and did Post-graduate studies at P. N. Labedev Physical Institute, Moscow. He initially did extensive work in electron paramagnetic resonance. N. G. Basov was a student of Prokhorov at the same institute, where he did major work on molecular oscillators.

During the war, Prokhorov was mobilised in the Red Army. In 1944 he returned to the Laboratory of Oscillation of the P.N. Lebedev Physical Institute and started basic research. Basov served in the Soviet Army during World War II. In 1945 he entered the Moscow Institute of Physical Engineering and studied theoretical and experimental physics. In 1952 Prokhorov and Basov jointly suggested the maser principle of amplifying and emitting coherent microwave radiation[38]. These Russian scientists had no radar experience like Townes, but had become interested in microwave as a means for spectroscopy.

Nicolaas Bloembergen (b. 1920), who had graduated from University of Utrecht, migrated to USA immediately after World War II and subsequently made great contribution in development of maser and laser. In his own words, "I arrived at Harvard University in February 1946, and became the first PhD research student of Professor Edward M. Purcell. He had just discovered, with R.V. Pound and H. C. Torrey, the phenomenon of nuclear magnetic resonance. My thesis "Nuclear Magnetic Relaxation" was submitted to the University of Leiden, since I had passed all my examinations in the Netherlands. The years 1946-1947 at Harvard were of course very exciting. I had regular discussions with Professors E.M. Purcell, J. H. van Vleck, R.V. Pound and Professor C.J. Gorter of Leiden, who was a visiting lecturer at Harvard in the summer of 1947"[39]. Bloembergen initially worked in the field of NMR. His joint publication with Purcell and Pound on basic theory of nuclear magnetic relaxation[40] is one of the most quoted papers in physics. The concept of negative absolute temperature introduced by their experiments found later application in the development of maser[41]. In 1956, Bloembergen produced a three-level solid-state maser, which introduced the pumping scheme later utilized in lasers[42].

In early fifties, inventors of microwave maser took major initiative to produce maser at shorter wavelengths. Charles Townes and Arthur Leonard Schawlow (1921-1999) of Stanford University had theoretically predicted in 1958 that maser could be made to operate in the optical and infrared region[43]. During the war years Schawlow taught classes to armed service personnel at University of Toronto, Canada and also worked on microwave antenna development at a radar factory. In 1958 Prokhorov and Basov et al also gave proposals for construction of laser[44,45]. Theodore Harold Maiman (1927-2007) an American physicist constructed the first practical laser unit in 1960 at Hughes Research Laboratories in Malibu, California[46].

The 1964 Nobel Prize in Physics was awarded to C.H. Townes, N. G. Basov and A. M. Prokhorov for fundamental work in the field of quantum electronics, which led to the construction of oscillators and amplifiers based on the maser-laser principle. N. Bloembergen and A. L. Schawlow were awarded 1981 Nobel Prize in Physics for their contribution to the development of laser spectroscopy.

Development of advanced NMR techniques

During early 1950s E. M. Purcell had predicted that NMR would be a tool for chemical analysis. However, for that to happen, it was necessary to increase sensitivity of the early NMR techniques. A major breakthrough in the field of NMR occurred when Swiss chemist Richard Robert Ernst (b. 1933) together with American chemist Weston A. Anderson developed a new method of high-resolution NMR[47] which increased the sensitivity of NMR spectroscopy many folds and made it possible to study small amounts of material as well as chemically interesting isotopes of low natural occurrence. For this contribution Ernst was awarded 1991 Nobel Prize in Chemistry. He also made contribution in high-resolution NMR, which paved the way for advent of two-dimensional NMR technique for macromolecular studies. Ernst and his colleague Kurt Wuthrich (b. 1938) at ETH Zurich, Switzerland, made first experiment of 2D NMR in 1977[48]. Wuthrich, through a number of experiments between 1977 and 1980, developed methods for identification and structure analyses of biological macromolecules. He was awarded the 2002 Nobel Prize in Chemistry. Both Ernst and Wuthrich had sufficient knowledge of instrumentation of NMR spectrometers. Ernst had himself constructed high-sensitivity radiofrequency pre-amplifiers and high-sensitivity probe assemblies for 25-MHz and 75-MHz proton resonance spectrometers at ETH Zurich, while Wuthrich working in Bell Telephone Laboratories in Murray Hill, New Jersey in 1967-68 was responsible for maintenance of the first superconducting high resolution NMR spectrometer operated at 220 MHz.

Discovery of magnetic resonance imaging

The technique of magnetic resonance imaging (MRI) for imaging human internal organs was discovered by American Chemist Paul C Lauterbur (b. 1929) at the State University of New York in Stony Brook, and British physicist Peter Mansfield (b. 1993) at the University of Nottingham. MRI is an exact and non-invasive method which marked a breakthrough in medical imaging and is perhaps the best example of application of a magnetic resonance phenomenon for human welfare[49,50]. Lauterbur and Mansfield were awarded the Nobel Prize in Physiology or Medicine in 2003.

Conclusions

World War II had great impact on the phenomenal advancement of magnetic resonance studies during the period from 1939 to 1973. The major factors which facilitated such advancement were alliance between USA and England for scientific and technical cooperation, large-scale involvement of physicists in these two countries for development of radar equipment, migration of physicists from Europe to USA and military funding for scientific and technical research during the war years.

Decision of the British and American Governments to conduct extensive research on microwave radar was the key factor for development of apparatus and techniques which were used extensively by the pioneers of magnetic resonance research after the World War II. Military funding for scientific research in USA and England during the war years and also during the cold war period gave a boost to this endeavour. Even during the period of cold war, the link between military institutions and fundamental research laboratories in physics, particularly in USA continued to expand[51]. Top grade physicists in USA and England who spent their war years in developing radar and wireless communication techniques and devices returned to basic research immediately at the end of the war.

Nazis rose to power in 1933 and as a result many physicists from Germany had to leave the country. Further, after devastation of Europe during World War II, many outstanding physicists were forced to migrate to USA. Here, within the purview of the present article, we consider the movement of three such pioneers, who subsequently earned Nobel Prizes for USA. Otto Stern, the Director of Physical Chemistry Laboratory at University of Hamburg, left Germany in 1933 and became a research professor of physics at the Carnegie Institute of Technology, Pittsburg, USA, where he worked up to 1945. Felix Bloch, originally from Switzerland, received his PhD degree from University of Leipzig in Germany. He continued research there, but when Hitler came to power Bloch left Germany in the spring of 1933. A year later he joined in Stanford University, Palo Alto, California as a faculty. He returned to Zurich, his birthplace, after retirement from Stanford in 1961. The Germans occupied Holland in 1940, while

Nicolass Bloembergen was a student at Utrecht University. He received a Phil.Drs degree (equivalent to MSc degree) from the University 1943. Nazis, however, closed the University the same year and Bloembergen emigrated to USA to join University of Harvard in 1945. He became a US citizen in 1958.

Starting from the path-breaking experiment of Stern and Garlach, which was the forerunner of magnetic resonance spectroscopy, seven Nobel Prizes in Physics, two in Chemistry and one in Physiology or Medicine were awarded within a span of 60 years in the field of magnetic resonance and allied branches of science. Out of fourteen recipients of these Nobel Prizes, there were ten Americans, two Russians, two Swiss and one British researcher. Further, from bibliographical survey[52] it transpired that developments of EPR and NMR during 1945-46 immediately drew attention of many physicist and chemists in various parts of the world, namely, in USA, USSR, England, France, Netherlands, Germany, Italy, Canada, Japan, Scotland, Switzerland, and India. During the following decade about seven hundred research papers on magnetic resonance were contributed by fifty laboratories, most of which were located in the USA.

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Presenting Indian Science and Technology Heritage in Science Centres

Part II

Shivaprasad M Khened

Continuing from where we left off in the first part of the article, in this second part a narration of how exhibits on the metallurgical heritage of India, have been showcased and the basis of choice of content and type and reasons for choice of display will be discussed. India has an outstanding heritage in metallurgy and its contributions in this field have now been universally accepted all across the world. Some of the master piece metallurgical heritage of India include the Delhi Iron Pillar[1] (4th-5th century AD), Dhar Iron Pillar, (10th-11th century AD) the long iron beams used in the Konark Sun temple (10th-11th century AD), Iron Cannons of Tanjore[2], internationally acclaimed Damascus swords that were made from the legendary Wootz Steel[3] from India etc and these are testimony to the mastery metallurgical skills of Indian metal craftsmen of yesteryears. Then there are these famous bronze statues from Tamilnadu, cast using the cire-perdue process, the tradition of which date back to several centuries[4]. The rich heritage of zinc smelting is unique to India since we were the first to smelt zinc in the world and also because zinc extraction was carried out in India on an industrial scale much before the Industrial Revolution.

National Science Centre was set up post the Exploratorium experience that took the world of science museums and centres by storm and therefore hands on approach to exhibits is one prime consideration for the Centre while designing exhibitions. Most of the science museums/centres set up across the world, our Centre included, that adopted the hands on approach espoused by the father of modern Science Centres, Frank Oppenheimer, unfortunately do not lay much emphasis on artifacts and also on historical subjects. This approach is also followed in most of the science centres in India and therefore artifacts, which form the heart of the history based exhibitions, is something which our centre unfortunately did not possess and therefore while covering a historical subject like the S&T Heritage of India, this major handicap had to be overcome with presentation styles that would partially make up for the absence of artifacts. With this handicap developing "Our Science and Technology Heritage" gallery at NSCD became more challenging and we had to rely more on creating content and letting our visitors understand what the achievement of India were through some innovative display and presentation techniques and presenting replicas in place of the original artifacts and creating period like setting with hands on multimedia presentations embedded inconspicuously in the exhibit. Notwithstanding the accolades that this gallery is continuing to receive from not just the lay visitors but also from scholars and museum experts we still feel that original objects/ artifacts would have greatly enhanced our presentation. In the absence of original objects or artifacts, we have tried to create as many replicas as possible and have used the replicas all across the gallery.

Metallurgical Heritage of India

The earliest records of use of metals in India date back to the Harappan times. The Harappan civilization gives ample evidence to a very high degree of metal culture[5] that is exemplified by the use of metallurgical objects made of gold, silver, lead, copper, bronze, and the famous statue of the dancing girl. The material evidence of use of metals in the Harappan civilization can be seen at the National Museum, New Delhi. A varied range of copper and bronze implements, weapons, household utensils and ornaments excavated and preserved in different museums in India and Pakistan points to a large scale exploitation of metals and to a flourishing industry of metal crafts during the Harappan times. Specialized technologies and the organization of crafts production and setting up of metal crafts centres in urban centres of the Harappan towns and other Indus settlements have paved the way for the continuing metal crafts traditions in India and Pakistan[6].

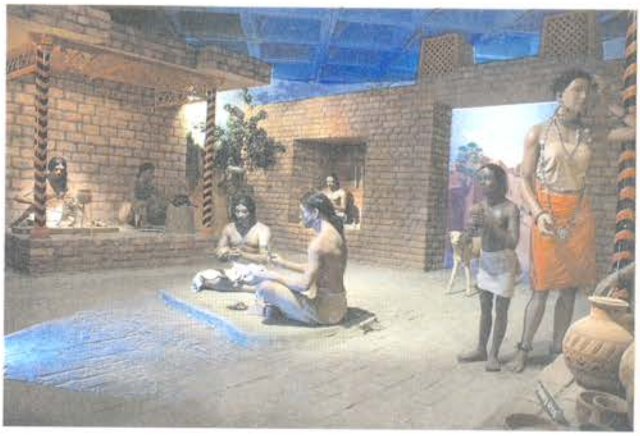


Fig. 1. A section of Indus Valley period room diorama presentation in the gallery showing metal craftsmen at work.

The story of metallurgical heritage in the gallery begins with an exhibit on the mining activities in ancient India. Mining in India has a respectable antiquity and dates back to the 3rd million BC. The mining activities from the Hutti (Karnataka) Gold mines and other extant finds from the mines of Rajpur-Dariba, Agucha, etc provide tell tale signs of extraction of ores from the mines in antiquity. Mining activities at a depth of 100 metres have been found in Rajpur – Dariba mines and C-14 carbon dating of these sites suggest that a thriving mining activities dating back to 1260 BC, 1130 BC and 1050 BC[7] was going on at this site. There are several other places in Gujarat and Rajasthan where large dumps of ancient slag are noticed which provide archeological evidence to the ancient mining activities in India[8,9].

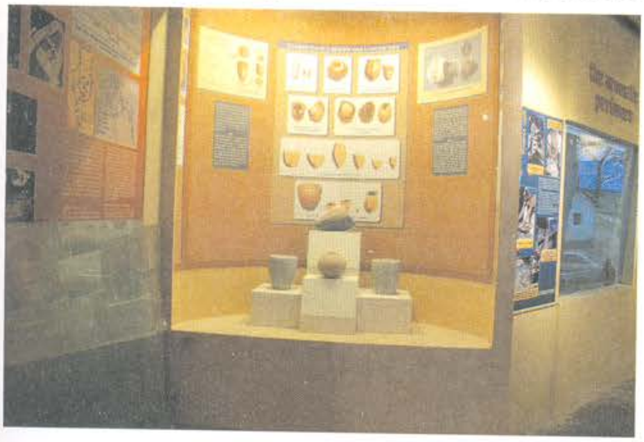


Fig. 2. Exhibit on the mining activities in ancient India with display of replicas of ancient crucibles.

Copper was one of the first metals to be extracted from nature and ancient mining activities for copper ore is seen all across India[10]. The earliest evidence of copper in India is seen from a cylindrical copper object from Mehrgarh which dates back to about 6000 BC. Several old copper mining sites with vertical shafts and open trenches have been found in Baleshwar, a site near to the Khetri site and even today Hindustan Copper Limited, a public sector enterprise of the Government of India, continues to extract copper from this site.

Iron and Steel

The United States Steel Corporation is considered as one of the authoritative sources of reference in the field of steel and in its tenth edition publication 'The Making, Shaping and Treating of Steel' it states *"Some authorities ascribe the original discovery of practical ferrous-metal manufacture to peoples in India at a very early date"*. This statement emphasizes the antiquity of Iron and Steel in India. Further more, the antiquity of Iron in India dating it to earlier than 1000 BC has been suggested in a publication in Nature[11]. The basis for this statement rests on three indisputable and enduring material evidence and symbols of Indian mastery over iron: the traditional iron making by the adivasis or tribes of India continuing as a living tradition to this day in Madhya Pradesh, the impressive rustless Iron Pillar at Mehrauli in Delhi and the invention of crucible steel making as early as 300 BC and continuing up to 1800 AD in Southern India and the forging of these steels into mighty swords, to become famous as the Damascus sword. Despite these recognitions, the date and origin of the beginning of iron workings in India has remained a much debated topic. Some of the scholars, especially those from the western countries, have suggested that Iron came into India from the West. This view has however been strongly contested by Chakrabarti who says "*there is no logical basis to connect the beginning of iron in India with any diffusion from the west, from Iran and beyond* ", and further "*that India was a separate and possibly independent centre of manufacture of early iron.*"[12]

From the radiocarbon dating of some of the iron bearing deposits at Ataranjikhera in Uttar Pradesh and Hallur in Karnataka, dates of around 1000 BC have been suggested[13]. Arun Biswas has further substantiated the antiquity of Iron in India based on both the archeological and literary evidences[14]. However, the antiquity of Iron in India is taken further back in age by Tiwari who suggests a date of 1800-1000 BC for the beginning of iron in India based on his excavations carried out in different parts of Uttar Pradesh[15].

In India, iron metallurgy has undergone a process of evolution, although there is very little data available by way of exact designs of ancient iron smelting furnaces, archaeo-metallurgical studies by scholars have helped in reconstruction of some of these furnaces. Most of the ancient traditions in India have transcended generations and some such technologies continue to be practiced even today by the tribal people. There are a number of tribal groups in India whose main occupation is iron smelting or related to iron working. These groups mainly classified as the Agarias, Asurs, Brijias and Lohars. The iron crafts tradition used by these groups is similar to the age old traditional methods which highlight the Indian traditional iron smelting technology.

Tribal Iron Furnace

One of the exhibits in the gallery is a model of the tribal iron furnace from the Bastar region, which has been

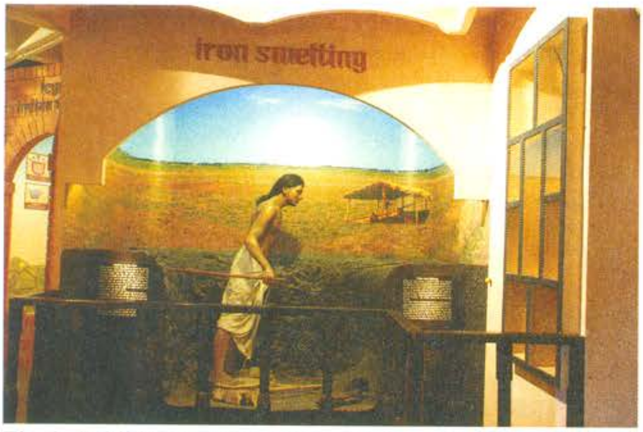


Fig. 3. Exhibit shows a reconstructed model of an ancient tribal iron furnace from the Bastar region.

reconstructed from references. These types of tribal iron furnaces are mainly used by the Agaria community. The Agarias, a special tribal community in MP and Chattisgarh, continue to smelt iron from iron furnaces whose design goes back to ancient times. The ancient iron furnaces in India have mainly been classified as *bowl shape furnace*, *dome shape furnace* and *shaft furnace*. The iron ores used by the Agarias are mainly hematite or magnetite that occurs in association with lateritic rocks in the form of heavy reddish brown stones. They break these stones into small pieces and clean them of sticking earth. They then mix the ore with charcoal in the proportion of 1:3 and this mixture of iron ore and charcoal is put into the furnace. The mixture is filled up to the top of the furnace and ignited and the mouth of the iron furnace is then plastered. After a continuous blast of one and half hour, the thick molten liquid starts appearing through the waste flute that indicates that the processes of melting of iron has begun. When the flow of slag stops, the bellows are removed. Finally, the bloom of glowing semi-molten iron balls are lifted out with the help of tongs and carried for hammering. After repeated hammering and heating, this iron ball is used for making various implements and household tools.

The techniques of making iron using ancient traditional methods from such furnaces have been very well documented[16,17]. Bastar district is inhabited mainly by two tribes Mundia and Haldi and in many parts of the district people continue to live on their traditional skills for their livelihood and make iron implements like arrow heads, axes and other agriculture implements using age old iron making methods. The *Agarias* of Chhattisgarh have preserved the ferrous technology tradition of early civilization. These people make pure iron by smelting the ordinary iron ore in very small furnaces which are located in their house-premises. The model used in the Tribal Iron Furnace exhibit is largely based on the furnaces used by the Agaria community.

Naikund Furnace

The exhibition also has a model of Naikund Furnace, which goes back to 700 BC. The excavations at Naikund has revealed special pottery and objects like sword, super head, arrowhead ladle, handled pan, chisel, spike, fish hook, horse bit and bangles etc [18]. The Naikund excavation[19] has also revealed the remains of an old iron furnace. Naikund furnace belongs to the category of shaft type furnaces. The diameter of the furnace is 30 cm and it is 25 cm in height. The base of the furnace was broad and it tapered at its opening on the top. The model of the Naikund Iron Furnace exhibited in the gallery is in the size of 2:1, amplified specifically with the objective of making it more clearly to the visitors. It was constructed with circular clay bricks and these bricks were piled one over the other, the upper surface of the lower brick was convex and lower surface of the upper brick was concave, thus they fitted into each other. A hole was provided at the bottom for tapping the slag. The furnace had two tuyeres, which were made of clay with a heavy mixture of quartz grains and measured 16 cm in length and 2.5/3.6 cm in diameter. These tuyeres were used to pass air into the furnace from the bellows. Two such tuyeres have actually been recovered from the excavation. From the remains of the iron slag that was excavated at site, it can be estimated that Naikund furnace could produce 3 to 3.2 kg of pure iron from 10 to 12 kg iron ore from a single operation. From the detailed archaeo-metallurgical studies, it is now certain that ancient iron smelters of Naikund developed a high level of metallurgical skills. The excavations of the Naikund furnace reveal a plethora of iron objects directly implying that a full time working group of ironsmiths existed at the site. Scientific investigations have been carried out on the objects excavated from this site and these studies have revealed existence of knowledge of steeling and hardening treatment around 700 BC [20].

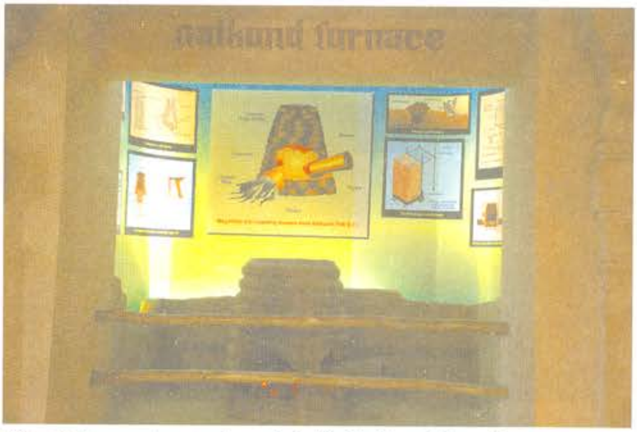


Fig. 4. Reconstructed model of a Naikund Iron Furnace which dates back to 700 BC.

Delhi Iron Pillar

The excellence of ancient Indian metal craftsmen is revealed from the Delhi Iron Pillar. In recognition of this unique feat achieved by ancient Indian metal craftsmen, Delhi Iron Pillar finds a special place in the gallery. The sight of the Iron Pillar standing in the courtyard of the Quwwat-ul-Islam mosque, adjacent to the Qutub Minar in Delhi, is breathtaking and cannot be missed by any visitor. The Delhi Iron Pillar is singularly featured on the emblem of the National Metallurgical Laboratory, a premier research institution working under the aegis of CSIR, at Jamshedpur, thereby signifying its prime identity as the country's metallurgical pride and heritage. The first detailed scientific study of the pillar was carried out by an eminent British Metallurgist Hadfield, in the year 1912. Ever since, there have been a growing number of studies in which several 'mysteries' of the pillar have been revealed. The Archaeological Survey of India studied the Delhi Iron Pillar with the cooperation of the National Metallurgical Laboratory (NML) in 1961. The results of these scientific studies were summarized in a special issue of the *NML Technical Journal (*Volume 5, 1963). A review of the pillar's corrosion resistance appeared in 1970. Professor T R Anantharaman, one of the doyens of modern metallurgy in India, has also published scientific facts about the pillar[21].

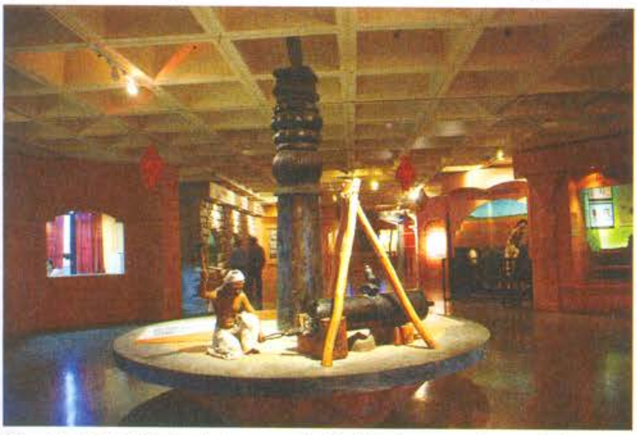


Fig. 5. Exhibit depicts an artistic 3D impression of the horizontal forging technique that was used in forging the massive Delhi Iron Pillar.

Although the present location of the pillar is in the precincts of the Qutub Minar complex, it is now very well established that this was not the original location of the pillar. The pillar was actually forged during the Gupta period around 5th Century AD using the horizontal forge welding technique and was originally located at Udayagiri, in present day Madhya Pradesh[22]. The Delhi Iron Pillar is testimony to the marvellous metallurgical knowledge that existed in ancient India. Scores of scholars from across the globe have studied as to how this edifice has managed to defy the natural laws of corrosion and remain rustless for more than 1600 years. It is in recognition of this marvellous character of the pillar that Anantharaman called it the Rustless Wonder. The unique quality of the pillar which has made it to remain rustless despite being exhibited in outdoor conditions are the right choice of the mix of material ingredients used in forging this pillar[23, 24]. This unique quality of the Iron Pillar makes it as one of the metallurgical wonders of the world. The exhibition has therefore a dedicated exhibit to show case the features of the Delhi Iron Pillar, which include its history, its manufacturing process, corrosion resistance, the bell capitol top, missing piece atop the pillar etc[25]. The exhibit in the gallery has a replica of the Bell Capitol Top of the Delhi Iron Pillar since this part of the pillar exhibits some outstanding metallurgical skills of the craftsmen who forged this marvellous part of the pillar[26]. The display is supplemented with scientifically rich information on various aspects of the pillar. The visitors can also notice a *Chakra,* an additional feature, on top of the Bell Capitol in the model displayed in the gallery while no such object is actually seen on top of the original Delhi Iron Pillar. This additional object, the *chakra,* has specifically been added on top of the Bell Capitol based on the research findings of Prof R Balasubramnium, who through his research findings has come to the conclusion that a Chakra object was actually on top of the original pillar and may have been displaced/lost on its transit while it was moved from its original location to Delhi[27]. Special emphasis has been laid on the Delhi Iron Pillar exhibit in the gallery and this exhibit finds a central place in the gallery mostly because the Centre is located in the city where the pillar is presently located and majority of the visitors may have actually seen the Delhi Iron Pillar yet they don't know how unique this

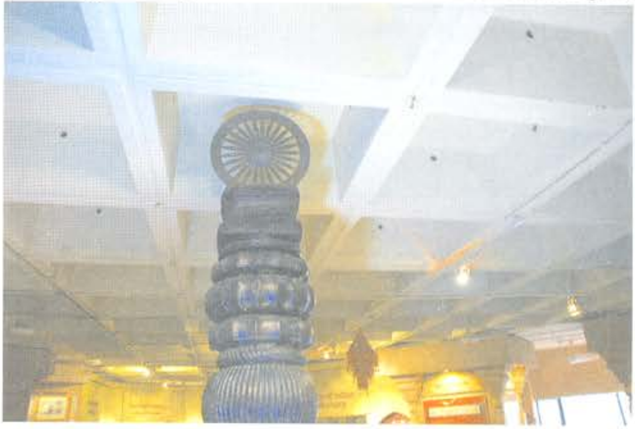
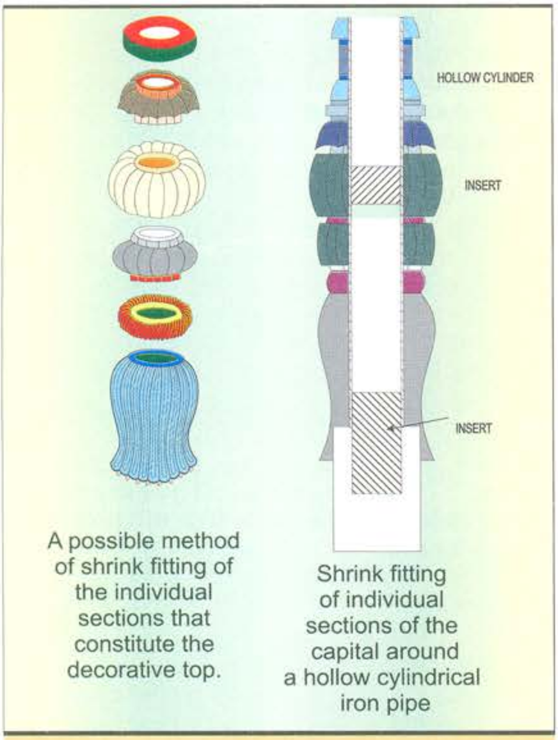


Fig. 6 A. The Bell Capitol Top with the missing Chakra atop the Delhi Iron Pillar.


HOLLOW CYLINDER
INSERT
INSERT
A possible method of shrink fitting of the individual sections that constitute the decorative top.
Shrink fitting of individual sections of the capital around a hollow cylindrical iron pipe

Bell Capital Top

The decorative top of Iron Pillar, known as Bell Capital, is a wonderfully engineered structure. This consists of seven distinct parts.

Fig. 6 B. Image shows the components of the Bell Capitol Top and the type of fitting technique used in fabricating the same.

object is and what are its specialties. The exhibit also has a scaled down model of horizontal forging technique, a method now confirmed to have been adopted for making this pillar[28].

Legendary Wootz Steel

Crucible steel making technique was developed primarily in South India and this led to the production of the legendary Wootz steel which was used to fashion the Damascus blades with a watered steel pattern that exhibited super-plastic properties[29]. Wootz steel production required precise technical knowledge since it had to be forged in a narrow range of 650^{0}-850^{0} C and not at the white heat of 1200^{0} C to get the desired fine grain structure and plasticity[30]. Because of this unique property, Wootz steel fulfills the description of an advanced material of the ancient world[31], since it is an ultra-high carbon steel which exhibits properties such as super plasticity and high impact hardness. It is for these special characteristics that this material of antiquity was highly sought after in different parts of the world and its special characteristics made it a right candidate for producing outstanding quality Damascus swords. Persians were among the major buyers of Wootz steel ingots from India which in turn were exported to the European countries from Persia. One such consignment exported to Dutch (Netherlands) from India consisted of 20000 Wootz steel ingots as recorded by T L Lowe.

The specialty of the Wootz steel is such that this material can not be surpassed even by advanced materials of the current era. The characteristics of this wonder material was so unique and intriguing that it found a special place in western science and scores of studies, including one by the legendary Michael Faraday[32, 33], were conducted on Wootz steel during the 18th and 19th centuries. Importance of the production of Wootz steel in South India can be gauged by the fact that by the late 1600s shipments running into tens of thousands of Wootz ingots were traded from the Coromandel Coast to Persia. The scale of production of Wootz steel was almost on an industrial scale in what was still an activity predating the Industrial Revolution in Europe. The popularity of this material can be further seen in the works of Arab scholars. Arab Edrisi, an Arab scholar of the 12th century mentioned that the Hindus excelled in the manufacture of iron and that it was impossible to find anything to surpass the edge from Indian steel. He further goes on to add that the Indians had workshops where the most famous sabres in the world were forged. There are also records from the Arab world where excellence of Hinduwani or Indian steel has been enumerated and this has been discussed in the works of Egerton[34].

It is in recognition of this unique contribution of India that an exhibit on Legendary Wootz steel finds a prominent place in the gallery. The exhibit contains a reconstructed model of a Buchanan furnace, known

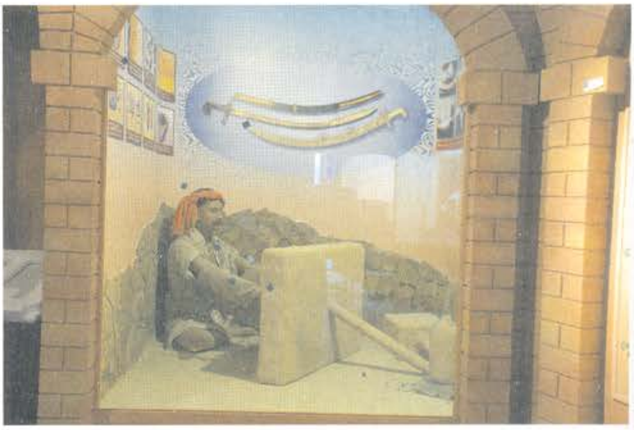


Fig. 7. A reconstructed model of a Buchanan furnace, known after Francis Buchanan, forms a part of the Legendary Wootz Steel exhibit.